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Center for Studies in Agriculture and Natural Resource Management

Faculty of Agronomy and Forestry Engineering. Eduardo Mondlane University

USAID | AGRIFUTURO Agribusiness Competitiveness

# USAID AgriFUTURO PROGRAM

## MOZAMBIQUE AGRIBUSINESS COMPETITIVENESS

# Invasive Fruit Fly (*Bactrocera invadens*): Occurrence and Socio-Economic Impact In Mozambique

Report Undertaken by CEAGRE for the USAID AgriFUTURO Project

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## Invasive Fruit Fly (*Bactrocera invadens*): Occurrence and Socio-Economic Impact in Mozambique

CONTRACT NO. 30464

Report presented to Abt Associates Inc to witness the

"Mozambique Agribusiness and Trade Competitiveness" program.

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## List of Acronyms

| | |
|---|---|
| CBA | Cost-Benefit Analysis |
| APHIS | Animal and Plant Health Inspection Service, USDA |
| SSA | Sub-Saharan Africa |
| COMESA | Common Market for East and Southern Africa |
| CTA | Confederation of Economic Associations of Mozambique |
| DSV | Department of Plant Protection |
| EAC | East Africa Community |
| EPPO | European and Mediterranean Plant Protection Organization |
| USA | United States of America |
| FAEF | Faculty of Agronomy and Forestry Engineering |
| INE | Mozambican National Institute of Statistics |
| MINAG | Mozambican Ministry of Agriculture |
| NPPO | National Plant Protection Organization |
| PARPA | Plan for the Reduction of Absolute Poverty |
| SADC | Southern Africa Development Community |
| TAM | Male Annihilation Technique |
| USAID | United States Agency for International Development |
| USDA | Unites States Department of Agriculture |
| FAO | Food and Agriculture Organization, United Nations |
| BAT | Baits Spray Application Technique |

# Executive Summary

## Fruit Fly as a Threat to Fruiticulture and Horticulture

Fruit flies are a threat to fruiticulture and horticulture causing losses in production around the world equating to billions of dollars (USDA, 2012; Sunday, no date). Over 4500 species of fruit fly exist around the world. They infest fruit trees (citrines, peach, mango, guava, etc.) as well as horticultural crops (pumpkins, cucumbers, pepper, piri-piri, tomato, etc.).

Fruit flies deposit their eggs in the interior of the fruit. The larva that emerge feed inside of the fruit causing damage and rotting. The infested fruit either falls to the ground early or loses its commercial value. It is through this process that the fruit fly causes damages and losses in production.

The various species of fruit fly are spread out differently around the world. This is why some species of fruit fly are found only in certain areas or continents. Due to this, countries impose restrictions on the movement of fruit and vegetables in and out of their country so as to avoid an alien species spreading itself in an area it previously never existed in and causing damages to the country’s fruit and vegetable production.

**EFFECTS OF FRUIT FLIES**

- **Losses in production by directly damaging the fruit of fruit trees and vegetables;**
- **Loss of markets both foreign and at home due to measures imposed to restrict the movement of fruits and vegetables.**

It was estimated that the horticulture sector in the provinces of Maputo and Manica could generate revenues of over 20 million USD annually (Cugala, 2011). However, this potential revenue could be undermined by the invasion and establishment of the invasive fruit fly, *Bactrocera Invadens*. Apart from direct export losses, job losses in the commercial sector would also occur and added to total losses. At the same time, the reduction in the production of fruits and vegetables in small scale farms will have a negative impact on both income and food availability for these rural families. All the while the high demand for fruit and vegetables in urban markets could cause an increase in the price of these goods.

## The Invasive Fruit Fly *Bactrocera invadens*

The invasive fruit fly, *Bactrocera invadens,* is originally from the Asia continent and until few years ago its spread had been restricted to only 3 countries (Bhutan, India and Sri Lanka) in

Asia. Since its detection in Kenya in 2003, this species has spread into 29 different countries all across sub-Saharan Africa. Only South Africa is free from this pest.

**THE INVASIVE FRUIT FLY *Bactrocera Invadens:***

- **Originated from the Asia continent**
- **Was first detected in Africa in Kenya in 2003**
- **Has dispered to almost every sub-saharan country, including Mozambique.**
- **Has yet to be spread to South Africa and for this reason South Africa has refused to import fruit and vegetables from any country which has detected this fruit fly.**

This fruitfly was detected for the first time in Mozambique in 2007 in Cuamba, Niassa. Currently it can be found throughout all of the central and northern regions of the country. Its presence and dispersion have brought the imposition of measures of quarantine by importing countries and domestic agencies that restrict the circulation and export of products, primarily fresh fruit and vegetables throughout the country (Cugala, 2011).

To deal with these quarantine restrictions, mitigate the impact of this pest, and assure access to fruit produced in Mozambique to international markets, various programs have been and are being implemented. These programs have been implemented by the Department of Vegetable Sanitation (DSV) the Ministry of Agriculture (MINAG), the Faculty of Agriculture and Forestry of the Eduardo Mondlane University in collaboration with the private sector and national and international investigation institutions with funding from the government and diverse agencies (FAO, World Bank, USAID).

Control measures for the invasive fruit fly put in place in Mozambique until now allowed the containment of the fruit fly in the area north of the River Save and made possible the maintenance of a zone free of the pest in the South of country for the last three years. Due to these control measures it has been possible to maintain the production levels and export of fruit from the South of Mozambique to South Africa. However, methods of control are quite costly. From the point of view of policy it is only sustainable to maintain these methods of control if the benefits that come with them can overcome current costs.

**TO AVOID THE SPREAD OF THIS PEST THROUGHOUT THE WHOLE OF MOZAMBIQUE DOMESTIC QUARANTINE RULES WERE DECREED**

**These measures were successful once the spread of the pest South past the river Save was stopped and the southern zone was declared pest free.**

**By accomplishing this the pest free zone could continue exporting its banana to South Africa its main market.**

### Objectives and Methodology

This study analyzed the economic effect of the invasive fruit fly in infested areas (Central and Northern areas of Mozambique) and in the non-infested areas (South of Mozambique – South of the River Save) separately. Based on primary and secondary data collection this study included:

- Collection of data covering the history of the fruit fly in Mozambique, including the evolution of the infestation, the control measures implemented, as well as other activities completed until now with the objective of mitigating the effects of this pest;
- Collection of primary data from the production and commercial sectors of the fruit industry;
- Analysis of the impact of the invasive fruit fly in infested areas;
- Analysis of the potential impact of the invasive fruit fly in non-infested areas;
- Cost-Benefit analysis of maintaining the southern part of the country free of the invasive fruit fly.

The primary goal of this study is to produce a document which informs policy makers, public sector financial priorities, and the businessmen and investors in the fruit industry about the impact of this pest in the country and the alternative methods of control and their implications for the fruit industry in Mozambique. This document then intends to call attention and raise awareness on this issue. It also intends to help in decision making to insure the continued growth of the fruit industry sector and realization of its potential.

## Primary Findings

The primary findings of this study are:

1. **The invasive fruit fly is a large threat to the fruit industry in Mozambique**, due to the level of production, market and job losses. The potential growth of the sector is at risk of not being achieved and various investments have been suspended.

> **The country has already lost more than 14 million USD in the infested areas, in particular due to:**
>
> - Loss of production (more than 440.000 USD/year)
> - Loss of markets and exports (more than 2 million USD/year)
> - Suspension of planned investment in the amount of 11 million USD, which prevented the predicted growth in production and export of fruit and a potential revenue loss of US$ 17.5 million per year.

2. **There is a high probability that invasive fruit fly will disperse to the south of the country**, where there are suitable conditions for its establishment.

> **If fruitfly invades the south of Mozambique, the banana export market to south Africa will be lost, causing losses of 17 milions usd loss per year and of around 5.000 jobs.**

3. Methods of control for the fly exist for the infested zones (North and Central) in Mozambique which will allow a substantial reduction in production losses from the actual levels of 72% lost to 5%. However, these measures alone will not be enough to eradicate the invasive fruit fly (as the fly has already dispersed to an extensive area), and declare the country free of the pest and thus recuperate export markets.

4. Quarantine (restriction of entry to the country and movement of hosts, monitoring and eradication of the fly on location as it is detected) is one method of control that helps avoid the entry and/or dispersion of the fruit fly throughout the country and, making it possible to declare the country or a specific region pest free. It is very important to reinforce the inspection and monitoring capacity in particular in the areas where entry (to non-infested areas) is possible and act timely to eliminate foci of insfetation as soon as they are detected.

5. Quarantine measures and control actions implemented in the country were correct and allowed the containment of the fly in the Northern part of the country. However, they were too slow and did not manage to contain or eradicate the sources of the infestation in that region (Northern Mozambique). Thus the fly has spread rapidly in all of the North and Center of the country and there is a great risk of its spread to the non-infested area in the South.

**The cost:benefit ration of maintaining the southern part of the country free of the fly was estimated at, at least 1:24. This result proves the advantages of the measures taken by the quarantine up until now. These measures allowed the country to maintain a souther zone free of the pest from 2007 until now.**

6. There is a large risk that other species of fruit fly invading the country in a near future. The species *Bactrocera latifrons* (which infests the fruits of the plants of the Solanaceae family) and *Bactrocera cucurbitae* (infests fruits of cucurbitaceous plants) were detected in Tanzania. The experience with the invasive fruit fly has resulted in an increase in the national capacity to deal with similar situations. This capacity should be taken advantage of and utilized to monitor and eradicate the introducion of these and other invasive species.

## Primary Recommendations

Based on the primary findings, this study recommends that:

- **Actions taken to control the pest should be continued and improved upon**. These actions, based on the experiences of other countries, should substantially reduce the population density of the invasive fruit fly and production losses to less than 5%, representing a 65% reduction in production losses. On the other hand the reduction of population density of the fly in the North and Central areas will also reduce the chance of the fly to spread south, allowing, with more ease, the maintenance of a free pest area in the South and the continuation of fruit exports from the south of Mozambique.

- **Quarantine should be continued and reinforced** which will enable the maintainance of the south of the country as a pest free area. It is necessary, not just to continue and improve the monitoring system based on traps already being implemented, but also to create an immediate response and control system in the case that fruit fly ocorrence is detected. Only with these systems of response and control of detected foci of infestation will be possible to avoid the fuitfly's dispersion and keep the southern zone free of the pest.

- **Research should be continued** concerning the efficacy and efficiency of the current control methods, new control methods, impacts on production and agro-ecology, as well as studies of the status of hosts of certain fruits like the green banana. This is the only way that it will be possible to improve the recommendations to the producers in such a way as to reduce the productions losse both in the commercial and family sectors.

- **Investing in and promoting the processing of banana and mango nationally** to compensate for the losses in exports. Currently in the North large volumes of produce are lost due to lack of domestic and foreign markets which is having a negative impact in the production. The processing is a possible alternative to increase demand in the national market.

- **Searching for international markets other than South Africa** for bananas and mangos keeping in mind the international restrictions and the possibilities of exporting green bananas to certain countries (once the green banana is determined not to be a host for the invasive fruit fly).

- **Improving the organization of the national fruit and horticulture sectors**. This sector has an enormous potential as a source of export revenue, as a source of prime material for the processing industry, as well as a source of income and food security for millions of families of producers and urban consumers. This sector is also very important on a social level through the amount of jobs it generates as well as the large number of farmers and families who produce and sell fruit and vegetables in the rural and urban markets and for their own consumption. All in all, it was identified in this study by the lack of existing information that this sector is not a priority for intervention and research and that there is no institution with MINAG that deals with the improvement of this sector. The lack of information gathered about this sector and the difficulty of timely action and allocation of resources by the State to aid the problem of the invasive fruit fly is evidence to this. Recommendations include: (i) increase the allocation of resources to carry on research; (ii) create an institution to co-ordinate and promote the fruit and vegetable sectors resembling the one in place for the cotton sector; (iii) improve the production of information directed at producers, exporters and investors about fruit crops and their areas of potential production; markets of exports; sanitary regulations, etc.

# 1. Introduction

The invasive fruit fly, *Bactrocera Invadens* (Drew), was detected for the first time in Mozambique in 2007 in Cuamba, Niassa. Its presence and uncontrolled spread imposed establishment of quarantine measures restricting the circulation and export of products, namely fresh fruit and horticultural products. These restrictions created losses in export and national markets (Cugala, 2011).

It was estimated that the horticulture sector in the provinces of Maputo and Manica could generate revenue in the value of more than 20 million USD annually through the commercial and household sectors (Cugala, 2011). All in all, this potential revenue is at risk of not being achieved due to the presence of the invasive fruit fly. In addition to this, jobs could also be lost from reduced commercial farming. The reduced fruit and vegetable production both in commercial and household farms, as a result of effect of the invasive fruit fly, could also have a negative effect on the income and food security of rural families. Also due to a high demand for these products in the urban markets, the reduced production could cause prices to rise to deal with scarcity.

To deal with these restrictions, imposed by the quarantine, to help in reducing the impact of the pest, and to secure access of fruit produced in Mozambique to international markets; diverse projects and steps have and are being taken. These steps were made by the Department of Vegetable Sanitation (DSV) and the Ministry of Agriculture (MINAG) in collaboration with the private sector and research institutions, both national and international, with funding from the government and diverse agencies (FAO, World Bank, USAID).

The progress in controlling the invasive fruit fly until now in Mozambique has allowed the containment of the fly North of the Save River and made possible the declaration of a pest free area south of the river for the last three years. By doing this it was possible to continue the production and export of fruit from the South of the country to South Africa. Overall, the measures of control are costly. From the point of view of policy it is only sustainable to keep these methods of control if the benefits outweigh costs.

The primary goal of this study is to produce a document which informs policy makers, public sector financial priorities, and the businessmen and investors in the fruit industry about the impact of this pest in the country and the alternative methods of control and their implications for the fruit industry in Mozambique. This document then intends to call attention and raise awareness on this issue. It also intends to help in decision making to insure the continued growth of the fruit industry sector and realization of its potential.

## 2. Background – Fruit Flies as a Threat to Fruticulture

### 2.1. Fruit Flies as Invasive Pests

Fruit flies are the most important pest affecting fruit trees, causing billions of dollars of losses in production annually around the world (USDA, 2012; Sunday, no date). This group of flies (which pertains to the Family Tephritidae) generally has colorful patterns on its wings and body. (Figure 1-A). From their eggs emerge the larva which feed on the interior of the fruit (Figure1-C and 1-D), deteriorating its quality. The areas where the fruit was perforated is where the larva feed and is conducive to the development of rots which lowers the quality of the fruit (Figure 1-B, 1-C and 1-D) and eventually cause them to fall to the ground. It is at this time that the larvae leave the fruit and go into the soil where they form pupas. From these pupas the adult flies emerge and begin the cycle of a new generation.

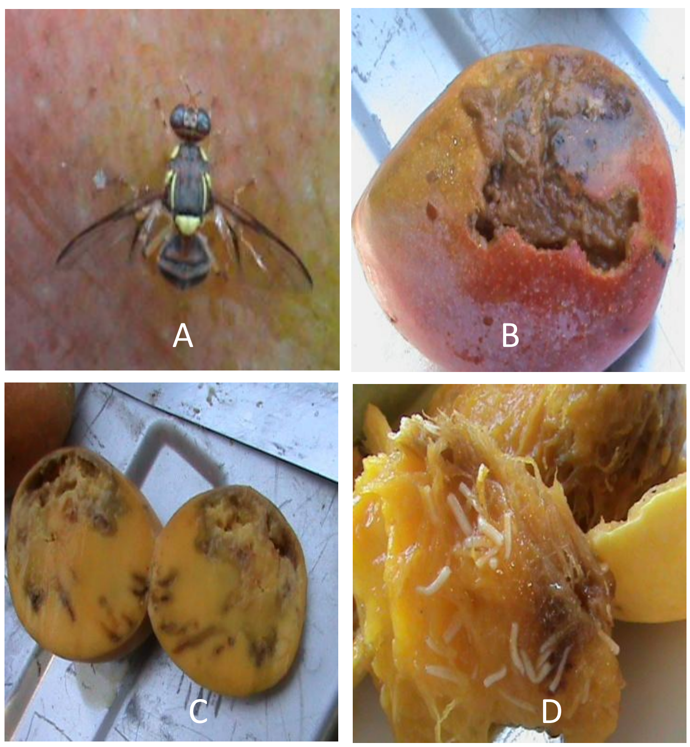


**Figure 1. Adult Invasive Fruit Fly and Damage Caused:**

A. Female *Bactrocera Invadens* laying eggs in a mango; B, C and D. Rotting and fruit fly larva in the interior of a mango(Source: Dr. Cugala)

There are about 4,500 different species of fruit fly worldwide, grouped in 484 genera. Some species are very polyphagous and attack various fruits from both fruit trees and vegetables (pumpkins, cucumbers, peppers, chilies, tomatoes, etc.). There are over 200 species of cultivated fruit and vegetables which can be infected by fruit flies around the world, the most important of which being the citrus, peach, mango and guava.

In Sub-Saharan Africa (SSA) there are approximately 915 species of fruit flies grouped in 148 genera. Of these, 299 species attack both wild and cultivated fruit. Many of these species attack important fruits and vegetables. The most important species belong to the genera *Bactrocera, Ceratis* and *Dacus* (Sunday, no date). For example, in mangos, samples taken in the SSA region show that the fruit is infested by various species of native fruit flies such as *Ceratitis Cosyra*, *C. Quinaria, C. Fasciventris, C. Rosa, C. Anonae,* and *C. Capitata* causing damage directly to between 40 and 80 percent of fruit depending on the location, variety and season of the year they attack (Sunday, no date).

Other than the damage done directly by the fruit flies to the fruits and vegetables (causing loss of production), they cause indirect losses due to the market restrictions imposed by the various countries of the world. The various species of fruit flies are distributed geographically which means each one of these species is found in only particular regions in the world. Due to this countries impose restrictions on the entry of fruit and vegetables to avoid the invasion of foreign fruit fly species. This way countries protect their fruit and vegetables producers and avoid production losses.

Despite Africa being the region of origin for many of the fruit flies which have invaded other continents, for example *Ceratitis capitata* which invaded Europe and America, many other species of fruit fly do not originate from the African continent. The frailty of the quarantine services in the African countries makes the continent vulnerable to the introduction of fruit flies not native to Africa. Examples of the invasion of fruit flies into the African continent are *Bactrocera zonata* in Egypt in 1997, *Bactrocera invadens* in Kenya in 2003 and more recently *Bactrocera latifrons* in Tanzania in 2006(Sunday, no date).

## 2.2. The Invasive Fruit Fly – *Bactrocera invadens*

Of all the fruit flies that have invaded the African continent, none of them have caused as much damage as *Bactrocera invadens*, the invasive fruit fly. Production losses of up to 85% have been recorded. Studies conducted in Tanzania, Kenya and Uganda where *B. invadens* was detected in 2003-2004, report mango damage in the amount of 40-80%, mostly in low altitude regions (Mwatawala *et al.,* 2006; Ekesi *et al.*, 2006 and Rwomushana *et al*., 2009). In Ghana, where it was reported in 2005, it caused damages to about 60-85% in mango depending on the variety and location (Ambele *et al.*, 2012). Meanwhile Benin also reports damages in upwards of 50% in mango (Vayssieres *et al.*, 2009). In Mozambique, in the region of Miese, province of Cabo Delgado, the damage to mangos was estimated to be around 72% (José *et al*., 2012). This direct damage caused by this invasive species in Africa is threatening the food security and way of life of millions of small scale producers all over Africa to whom these fruits are a main source of income.

The invasive fruit fly has also affected the export of the fruits it infests. The imports of mango, avocado and cucurbits from Kenya, Tanzania and Uganda were banned by Seychelles, Mauritius and South Africa. The United States of America recently released an order prohibiting the import of fruits and vegetables from African countries where this species has been found. (Sunday, no data). The imports of mango, banana, tomato, and chili from the North of Mozambique have been banned by South Africa.

The invasive fruit fly infects more than 75 species of plants, preferring the mango. Other species it is commonly found infecting include: guava, citrus, papaya, tomato, banana, annona and other wild African fruit such as massala (Ekesi and Billah, 2007; De Mayer *et al.,* 2012; EPPO, 2012). A complete list of host fruit for the invasive fruit fly can be found in Annex 4.

The species *Bactrocera invadens* originates from the continent of Asia and until a few years ago its occurrence was restricted to only three countries (Bhutan, India and Sri Lanka) in Asia. Since it has been detected in Kenya in 2003, this species has dispersed to various countries including but not limited to: Angola, Benin, Burkina Faso, Cameroon, Chad, Congo, Comoros, Ivory Coast, Democratic Republic of Congo, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Mozambique, Niger, Nigeria, Senegal, Sierra Leon, Sudan, Tanzania, Togo, Uganda and Zambia (EPPO, 2012; CABI, 2012) (Figure 2).

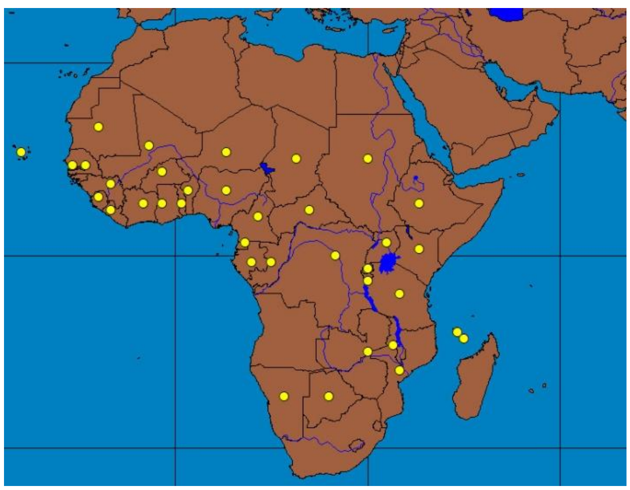

**Figure 2. Map of the Geographic Distribution of *Bactrocera* Invadens** (Source: De Mayer *et al.*, 2012)

## 2.3. Strategies Used World Wide for Fruit Fly Management

To reduce the damage caused by fruit flies the use of various methods is recommended, combined in a package of integrated management, which may include:

1. Practices at the producer level to diminish the infestation of fruit flies such as:
    - Spraying with toxic baits(mixture of attractant and insecticide);
    - Sanitation that includes the collection and destruction of fallen fruits;
    - Use of an "augmentorium", a tent-like structure that contains the infested fruit and sequesters the adult flies but allows the escape of parasitoids;

- Physical protection of the fruits using newspaper or paper bags;
- Timely collection(once physiological maturity is complete);
- Post-collection treatment that consists of submitting the fruit to heat, cold or radiation to kill the flies in the interior of the fruit.

**2.** Regional methods of control being implemented by public institutions or public/private partnerships which include:

- Male annihilation technique(TAM) which consists of the placement of traps, at elevated densities, which contain products attractive to male flies(such as Methyl Eugenol, GF120) mixed with an insecticide;
- Sterile male technique which consists of the liberation of an elevated number of sterile males into the environment. When females mate with these sterile males they produce eggs which do not develop into larva, progressively reducing the population of the species potentially eradicating it. The males are generally sterilized when they are submitted to radiation (X-ray), which is done in a laboratory before the release of the fly back into nature.
- Biological control with the use of parasitoids *(Fopius arisanus* and *Diachasmimorpha longicaudata*), predators (weaver ant, *Oecophylla longinoda*), pathogenic fungi such as *Metharhizium anisopliae* without forgetting the principles of conservation of biological control agents (reduction of application of pesticides and *augmentorium*);
- Quarantine which consists of: monitoring based on use of traps to capture males and to detect occurrence, restrictions on the entry and movement of the host fruits and vegetables, inspections at borders and main travel and commercial routes and rapid elimination of infestations once they are found and divugation.

Many of the above mentioned strategies have already been tested for the invasive fruit fly, *B. invades*. In some African countries they have shown promising results (Eleis, no date). One study published in June 2008 reported reduction in the damage caused by the invasive fruit fly in up to 17% of Senegal with the use of collection of fallen fruit, the use of toxic baits(attractant GF120 mixed with an insecticide) and mounting traps based on methyl eugenol mixed with malathion(Ekesi, no date). In Kenya, the strategy has been based on continuous monitoring with attractants followed by the use of toxic baits, TAM, bio-pesticides, liberation of parasitoids, cleaning of fruit farms and the use of *augmentorium*. By means of these methods the losses in fruits were reduced by more than 70% and the quality of fruit was improved resulting in good prices in markets in the regions where it was implemented (Nguruman, Runyenjes, Meru and Malindi) (Ekesi, no date).

Various success cases in controlling the different species of invasive fruit flies have been documented in the world, using a combination of the various methods described. In Taiwan(Asia), it was possible to reduce the loss of fruit annually from 90% to 5% caused by the oriental fruit fly *Macrocerodrosais* (Handel) introduced in 1911(Quo, no date) using the male annihilation technique(TAM). In Mauritius *Bactrocera zonata* (the pear fly) was introduced in 1942. Using the technique of toxic baits followed by TAM amounts of lost fruit were drastically reduced (Sookar *et al*., 2006). In 1996, while this program was on going, accidentally another fruit fly species was introduced from quarantine, the oriental fruit fly *Bactrocera dorsalis* (Hendel). The existing material, equipment and training personnel already gathered allowed a rapid intervention (within 24 hours of detection) with such efficacy that the invading species was declared eradicated in 1999. With the solution being the same techniques used previously (toxic baits, TAM and proper sanitation of fruit farms) (Sookaer *et al.,* 2006). This experience shows that proper sanitation of fruit farms should be integrated to increase the efficacy of this system of control. Studies are also being done to attempt and make the sterile male technique more sustainable. The program has divulgated this information and to educate the public and producers alike, posters have been made as well as lectures at schools and audiovisual mediums (Sookar *et al*., 2006).

On the island of Hawaii, a Mediterranean fruit fly *Ceratis capitata* (Wiedemann), the melon fruit fly *Bactrocera cucurbitae*(Coquillet) and the oriental fruit fly *Bactrocera dorsalis* were introduced and became the largest economic pest threat in the production of fruits and vegetables(Vargas *et al*., 2010). A partnership between the Project for Fruit Fly Management and the Hawaii Agriculture Research Center resulted in a successful program, which controlled the fruit fly which had been devastating agriculture for more than 10 years. The program was based on a package developed by the Hawaii Agriculture Research Center which combined sanitation/cleanliness (of fruit farms), toxic baits, as well as TAM and sterile male technique. The Hawaii Agriculture Research Center, the Hawaii Department of Agriculture, the University of Hawaii as well as rural communities with the support of APHIS and other government agencies had to band together in order to implement the program to deal with the fruit flies. The program covered 6,798 ha and 491 areas of production of fruit and vegetables. This resulted in a reduction of the use of conventional pesticides by 57-90% and a decrease in infestations from 30-40% to less than 5%. The small producers which had abandoned farming due to the flies returned to production.

In all of these cases, the partnerships between the government, NPPO’s (national agricultural authorities), research institutes, the private sector and farmers was necessary. On top of this the creation of a work force for the fruit fly initiative was crucial to the success of these implemented measures.

In the case of the invasive fruit fly, *B. invadens*, all the African countries involved in the fight against fruit flies realize that the solution to this issue is a regional one (Ekesi and Mohamed, 2010). In May of 2010 a video conference was held (organized jointly with the World Bank) which united Ethiopia, Kenya, Mozambique, South Africa and Tanzania to discuss their answers for the threat posed to the production of their fruit and vegetables by the invasive fruit fly species *Bactrocera invadens*. At the conference it was deemed that of all the countries that are bordering South Africa, Mozambique certainly is most affected due to the large project for banana production currently underway in Nampula (Ravry, 2010).

The documents prepared for this conference suggested an urgent necessity for the countries to reunite to prepare a coordinated response, under the scientific leadership of ICIPE (as an institute of research and regional training) and of a regional institution (EAC, COMESA and SADC) in order build up the momentum needed for these countries to move forward. This because it has become apparent that if each country works in isolation attempting to manage a pest of this type(with elevated ability, flight and no respect for international borders) the success of the programs may be compromised. The role the private sector plays, stimulated by economic interests, is the key to lead the response and also stimulate the farmer community to participate in the monitoring of *Bactrocera invadens*. In the same video conference it was made clear that the way forward should without doubt include debates over the necessity of a greater sense of urgency on the part of the NPPO's, which is recognized as a base condition in gathering more support from regional organizations and donors.

## 2.4. The Importance of the Fruit Sector in Mozambique and the Risk of Infestation by the Invasive Fruit Fly

The agricultural sector is a key part in economic growth, food safety and the reduction of poverty in Mozambique. It is an important source of employment as well as revenue for the government provided by the export of agricultural products (Cunguara and Garrett, 2011).

Agriculture is main source of income for Mozambicans, employing more than 80% of the population (95% of which live in rural areas) and contributing to approximately 25% of Mozambique's Gross Domestic Product (GDP) (INE, 2010). In the period from 2004 to 2010 an economic restructuring and subsequent adoption of PARPA resulted in an high economic growth, estimated at approximately 7.5% per year (INE, 2011). The agrarian sector showed a rate of growth even larger, estimated at 8.4% increase of revenue and production (mainly due to the expansion of cultivation areas and a crop diversification) (Cunguara and Garret, 2011).

Agricultural products contribute to approximately 47% of value of exports in the country, excluding the large projects reaching, in 2011, a value of 370 million USD (Cugala, 2009). The main agricultural products Mozambique export include sugar, cotton, tea, cashew nuts, citrus, banana, tobacco, beans, sesame, copra, and copra oil, sisal, soy and mango (IPEX, 2012). Among these export crops the most vulnerable to the invasive fruit fly threat are the banana and mango.

The export of tropical fruit such as banana and mango has come to increase in the last years (IPEX, 2012) having reached, in 2009, a value of 4.6 million dollars (Table 1.) This sector has also been receiving considerable investment. The primary external markets for export of these fruits are the European Union (Portugal, Belgium, and Spain), the Middle East, SADC (mainly South Africa, Zimbabwe and Malawi) Switzerland and Japan.

**Table 1**. Evolution of the Value of Exports of Banana and Mango in Mozambique from 2006-2009

| Year | Value of Exports(thousand dollars) | |
|---|---|---|
| | Banana | Mango |
| **2006** | 1,671 | 163 |
| **2007** | 3,883 | 290 |
| **2008** | 5,377 | 154 |
| **2009** | 4,492 | 151 |

Source: Contrystat (2012)

Of the agricultural products, banana is actually one of the fruits with the most economic significance for the Mozambique (Cunguara and Garret, 2011). Before independence, Mozambique was one of the largest exporters of banana to South Africa with volumes varying between 20 to 25 thousand tons per year (Sale and Pita, 2009). In the last years the commercial cultivation of banana has been growing; exports increasing from 29 thousand tons in 2009 to 77 thousand tons in 2011 (DSV, 2012).

Banana is essentially produced commercially by 8 large companies and some small producers in the provinces of Maputo (Boane and Maputo) Gaza, Manica and Nampula as well as by family sector particularly in the region of Macate in Manica. The large producers of banana supply the markets of large domestic cities such as Maputo, Matola and Beira and also export to South Africa, the European Union and the Middle East. The average production of banana is currently estimated at 6.4 tons/ha for the family sector (Uazire *et al.*, 2008), and 45 tons/ha for the commercial sector (A. Gomes, personal communication).

Mango is also produced on a commercial scale in the provinces of Manica (district of Sussundenga) and Maputo. The Mango produced in Manica, which reached a volume of 400 tons in 2011, is exported to South Africa, Zimbabwe and countries of the European Union. The majority of areas of mango production, particularly in Manica, are new and many fruit farms have yet to begin producing.

## 3. Objectives of the Study

These are the objectives of this study:

a. To describe the entire history of the invasion of the fruit fly in Mozambique and the methods of control realized in Mozambique, identifying the principle players in these activities;

b. Analyze the current situation of occurrence of the invasive fruit fly and the effect of the methods of control used;

c. Estimate the impact caused to the country to date by the invasive fruit fly in the commercial agriculture sector;

d. Analyze the cost-benefit ratio of maintaining the South of the country non-infested;

e. Produce reccomendations on actions needed to mitigate the invasive fruit fly problem in Mozambique.

# 4. Methodology

At the moment, southern Mozambique is considered free of the fruit-fly, while the central and northern regions are infested by the pest. This study analyses the economic impact of the fruit-fly in the infested regions (central and northern) and in the free region (southern Mozambique – south of the Save River). Four analytical pieces were prepared to achieve the objectives of the study:

- Collection of historical information on the fruit-fly in Mozambique, including the evolution of the infestation, the measures implemented to control the pest and other activities implemented up-to-date to mitigate the effects of the pest;
- Collection of primary data from the commercial fruit sector;
- Analysis of the impact caused by the fruit-fly in the infested regions;
- Analysis of the potential impact of the fruit-fly on the pest free region and of the cost-benefit to maintain the southern region of the country free of the fruit-fly.

## 4.1. Collection of Secondary Data

A literature review on the fruit-fly was prepared, including both research in and out of the country aiming at collecting positive experiences in dealing, combating/controlling and/or exterminating the pest in others countries. This information helped to evaluate, in relative terms, the incidence of the fruit-fly pest in Mozambique. This also allowed to evaluate the "position" of Mozambique relative to the Southern African countries, in particular, and to the world in terms of the level of incidence and measures taken to mitigate the pest.

The collection of historical data on the fruit-fly mainly included:

a. When pest was introduced in the country as well as in Southern Africa;
b. Current status of the pest and degree of infestation of the fruit-fly in the country;
c. Measures taken to control the dispersion of the pest in the country, as well as to reduce the loss of production caused by the pest.

The evaluation of the occurrence of the pest in the country was prepared using data collected from traps used by the partners (DSV and private companies), as well as data recently collected during research studies done by researchers of the Faculty of Agronomy and Forestry Engineering in the Province of Cabo Delgado.

The density, incidence and severity of the pest were used to evaluate the level/degree of incidence of the pest. The density of pest is determined by the total number of adult fruit-flies captured by the traps divided by the number of days that the trap was in the field and again by number of traps inspected. The pest incidence is the percentage of the total number of infested fruits over the total number of fruits observed. The severity of the pest is the total number of adults and pupae of fruit-flies in each kilogram of estimated fruit production determined by the following formulae (Vayssiéres *et al*., 2009):

a. Rate of infestation (Ti ) = Number of pupae/kg of fruit
b. Index of infestation (Ii) = Number of adults/kg fruit

## 4.2. Collection of Primary Data

The primary data was obtained through surveys and interviews in the provinces of Maputo, Gaza, Inhambane (southern region), Manica (central region), Nampula and Cabo Delgado (northern region). The target-group was defined as the commercial private producers of mangoes and bananas and public institutions involved in activities of monitoring and control of the fruit-fly in the country.

Taking into account that the number of commercial producers of fruit in the provinces covered by the study (Maputo, Gaza, Inhambane, Manica, Nampula, e Cabo Delgado) is not large, the study made a census of the commercial producers instead of considering just a sample. For the provinces included in the study, to identify the producers to be included in the census, a list of all the commercial producers of mangoes and bananas was prepared with information supplied by DSV, DPAs and CPI.

The collection of data from the commercial fruit producers of mangoes and bananas was done using an interview guide semi-structured for individual producers of the infested regions and for the freely-infested region (Annexes 1A and 1B, respectively). This instrument allowed the collection of data for:

a. Perception of each producer relatively to losses of production caused by the fruit-fly;
b. Total volume of production;
c. Percentage of production loss due to the fruit-fly;
d. Quality of the produce (prices);
e. Markets of production destination and loss of markets;
f. Methods adopted to combat/reduce the negative effects of the pest;
g. Costs associated to adopted control methods (costs of materials, human and capital);
h. Costs associated with the pest (frequency of visits to the traps, human resources and material used), through a complementary survey (Annex 1C).

The family sector normally produces under rainfed conditions and the producers do not keep production records. The time and budget of this study did not allowed for a survey of the family sector to be carried out and, for that reason, the impact of their food security was indirectly estimated through the reduction in the number of months of fruit availability in the local markets using a survey to the fruit market participants in some districts (Annex 2). The selection of districts in each province where the study was done took into account their fruit production potential.

The collection of data from the public institutions intervening in the process of control of the fruit-fly included DSV, FAEF, DPAs, SDAEs and CPI, at the provincial level. The information related to costs of the control actions implemented by the government's institutions was supplied by DSV. Information regarding volume of fruit exports was supplied by DSV (export licences).

## 4.3. Methodology for the Analysis of the Impact of the Invasive Fruit-Fly in Mozambique

### 4.3.1. Impact of the Invasive Fruit-Fly in the Infested Region

The impact analysis of the invasive fruit-fly used the following evaluation indicators: (i) production loss, (ii) export loss (quality), (iii) market loss, (iv) food security loss, (v) increased government expenditures and of production costs of the commercial companies due to the implementation of control measures, (vi) reduction of jobs and (vii) losses related with non-realized investment due to the presence of the fruit-fly.

The benefits of the control methods used in the infested region were not estimated since there are not data on the efficacy of the main control method implemented by DSV in terms of the reduction of the pest's population and production loss. The method consists on biological control through the breeding and launching of a parasitoid.

### 4.3.2. Potential Impact of the Fruit-Fly in the Free Area (Non-Infested) and Cost-Benefit Analysis (CBA) of Maintaining the South of the Country Infestation Free

Several studies of the fruit-fly point to the cost-benefit analysis (CBA) as the most practical method to assist with decision-making on the methods to control invasive pests in a defined region, taking into account the potential loss that invasive plagues can cause to the region such as the use of control measures to keep the region free (Harvey *et al*., 2010; e Florec *et al*., 2010). This study used the CBA and uses the following indicators of cost and benefit:

1. **Costs:**
    i. Implementation of a monitoring system of the pest to reduce the time to alert for the occurrence of the pest and take timely measures to contain the pest when needed (see detailed methodology for the calculation of monitoring costs in Annex 3);
    ii. Implementation of quarantine measures, including measures to contain/eradicate spots which could occur in the non-infested pest region;

iii. Loss of markets and production by the producers in the infested region (northern) as they will not be able to sell fruit to the southern region of the country.

2. **Benefits:**
   i. Export value to South Africa and loss of potential exports in the case of presence of the pest and exports being banned;
   ii. Production value “saved” if the loss of production occurred in case of presence of the pest;
   iii. Control costs (public/government or private) needed if the pest was present;
   iv. Maintaining and increasing number of jobs;
   v. Increase of production and exports from new investments that would be cancelled if the pest invades the free region.

# 5. History of the Invasive Fruit-Fly (*Bactrocera invadens*) in Mozambique

## 5.1. Initial Detection of the Fruit-Fly in Mozambique

In March 2003, during regular monitoring of the fruit-fly by ICIPE part of the African Fruit Fly Initiative (AFFI), specimens of fruit-fly up-to-then unknown were found in Kenya (Ekesi e Mohamed, 2010). Lux *et al.* (2003) based on morphological characteristics covered from the dorsalis complex, specifically *Bactrocera dorsalis* (Ekesi e Mohamed, 2010). Immediately to its detection in Kenya, the species was reported in many other African countries. Specimens were later sent to Prof. Dick Drew in Australia, who identified and described them in 2005 as *Bactrocera invadens* (Diptera: Tephritidae). The time and exact trajectory of the invasion of the *B. invadens* in Africa are still unknown (De Meyer *et al.* 2009).

According to Correia *et al.* (2008) and Cugala and Mangana (2010), in Mozambique *Bactrocera invadens* was detected for the first time in the district of Cuamba, province of Niassa, in July of 2007. Afterwards, the detection of the pest followed the sequence of cases: Vanduzi-Manica (August 2008), Pemba-Miese and Alua-Nampula (October 2008), Chimoio-Manica (September 2009), Zobue-Tete (February 2010), Zambezia, Dondo-Sofala and Dombe-Manica (March 2010) and Muxungue-Sofala (June 2011).

## 5.2. Immediate Consequences of the Introduction of the Invasive Fruit-Fly in Mozambique

Due to its invasive, destructive and restricted geographic distribution, the *Bactrocera invadens* is considered a quarantine species in many countries in the world. Then and when it was detected in 2007, Mozambique lots its status of free region and, consequently, lost access or suffered restrictions in access to international markets for all products that could host this species. Then, in 2008 South Africa announced the suspension of imports of fruits and vegetables produced in Mozambique. In February 2010, the Zimbabwean government temporarily closed its borders to imports of fruits and vegetables from Mozambique (Cugala and Mangana, 2012).

The temporary closure of access to the South African market in September for 1 month resulted in the loss of US $2.5 million (Cugala, 2011). The Vanduzi Company, Manica province, registered a loss of about US $1.5 million. In the same period, in Maputo province, 4,000 people ran the risk of losing their jobs. This environment discouraged investments in the horticulture sector particularly in Manica province. These were indications that the presence of the *B. invadens*, beyond generating direct economic losses to the production would also have negative impacts on the reduction of exports and social impacts such as the loss of jobs. In addition to the reduction of production and exports, the pest would also decrease rural families' incomes through the reduction of their sales and would decrease food security (Cugala, 2011).

### 5.3. Measures Taken to Reduce Infestation after the Detection of the Invasive Fruit-Fly

In face of the invasion of the *B. invadens*, the Ministry of Agriculture (MINAG) through its Department of Plant Protection (DSV), Department of Agronomy and Forestry Engineering (FAEF) of the Eduardo Mondlane University, the private sector and partners of cooperation since 2007 have been launching mitigation/contention actions of the invasive fruit-fly in the country. Financial support was requested from The World Bank and FAO to establish a monitoring program in different areas of risk.

The Department of Plant Protection (DSV), to avoid the dispersion of the pest from the affected to the non-affected areas, established in 2007 domestic quarantine measures to internally control the movement of products hosting the pest (Cugala and Mangana, 2010). The movement of fruits and vegetables was banned within the country and fiscalization posts were set in the main roads and means of communication (Bridge Armando Guebuza—Zambezi River, Machipanda border, Inchope intersection, Save River bridge, Limpopo (Xai-Xai) and Incoluane bridges).

At the same time, a working group was created for the fruit-fly, the "**National fruit fly steering committee"**, including members from the MINAG, DSV, FAO, FAEF, private sector, CEPAGRI, development agencies from cooperation partners and NGO's and projects such as AgriFUTURO/USAID and TechnoServ (Cugala, 2011). This working group has the responsibility of discussing issues related to the fruit-fly and propose recommendations. The group is chaired by DSV, which is in-charge of monitoring, administration and decision making activities related to this pest and vegetal health in the country.

Since October 2007, FAEF and DSV in collaboration with the private sector and support from USDA/APHIS (Pretoria, South Africa) and assistance from the Royal Museum for Central Africa (Tervuren, Belgium) have been monitoring the fruit-fly presence through the establishment of a network of traps using methyl eugenol pheromones. The total number of traps has been gradually increasing and currently has 372 traps in 289 places in areas considered of risk in the entire country (Cugala, 2011). These monitoring activities mainly focus on the key roads and routes of transportation (road North-South, from Pemba and Tete to Maputo; and from West to East, from the Zimbabwe border to Beira), as well as in the main fruit production areas in Nampula, Manica, Inhambane, Gaza and Maputo. Traps have also been set in many different places such as fruit orchids, villages, and markets and along main highways (Figure 6).

The monitoring results in the country show that, in 2012, the North of the country is an infected region, the Central region has a low prevalence of the pest, while the Southern region is a pest free region (Cugala and Mangana, 2010) (Figure 5). It has also been observed that the species occurred at high population density in the provinces of Cabo Delgado, Nampula (Namapa, Alua, and Nampula city), Niassa (in particular in Cuamba), Zambezia (Lioma, Guruè, and Alto Molócuè), and Tete (Zóbue, Malawi border). The occurrence of *B. invadens* exists in high density in all northern provinces and decreases as it goes to the South, and the evolution of the pest's occurrence along the time might be an indication that the species was probably introduced in the north via Tanzania or Malawi and is currently dispersing from the north to the soul, and rapidly (Figure 5).

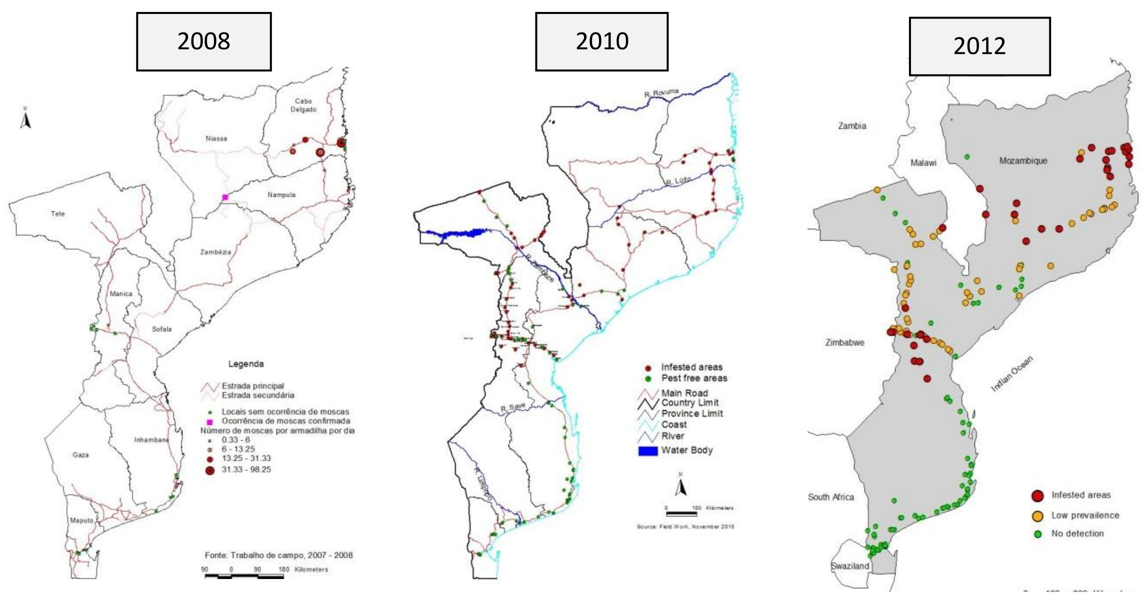


**Figure 3.** Evolution of the number of traps (monitoring) and occurrence of the fruit-fly in the country during 2007-2012 (Source: Cugala and Mangana, 2010)

This monitoring allowed the understanding of the evolution of dispersion/spread of the invasive fruit-fly in Mozambique. It has been critical to show that occurrence is non-existent at the South of the Save River, permitting to call that region free of the pest. As a consequence, it was possible to lift up the banana import banning from South Africa for products from this southern region. Monitoring and domestic quarantine actions developed by these institutions have slowed down the dispersion of the fruit-fly along the southern region of the country, up to this moment.

## 5.4. The Role of the Various Involved Parties

The different intervenient in the process were:

**DSV – Department of Plant Protection, MINAG (DSV**) – As the national authority to protect plants has been developing a key role in the definition, implementation and management of measures and operations of quarantine (fiscalization, communication, coordination with other government institutions), preparation of reports and official newsletters on the fruit-fly, coordination of the working group, declaration of the free region and keeping communication with the neighboring countries and dissemination of information, and in finding funding and projects.

**FAEF – Faculty of Agronomy and Forestry Engineering, UEM** – They performed a critical role on the identification of the species, management of the network of traps for monitoring of the pest's occurrence, development of research on control methods, looking for finance and preparation of key reports.

**Commercial fruit producers and their associations** - These were critical in the monitoring of the occurrence of the fruit-fly in their orchids in the implementation and test of the control measures and in the discussion and dissemination of the situation of the pest and in estimating the impacts on their production and export as well as on lobbying with governmental agencies and groups of interest.

**Regional and international entities for Plant Protection** (USDA, APPHIS, NPPOs from neighboring countries) – These developed an important role in the coordination of regional activities, exchange of experiences on control measures and technical counseling.

**Agencies, of development and financing** (FAO, World Bank, USAID/AgriFUTURO) – They played an important role in financing, advising and lobbying. Various projects have been and are being undertaken.

The case of the invasive fruit fly represents a positive experience in coordination and complementary activities between the various intervenients involved. Of note the creation of a labour force for the fruit fly which is itself a forum (though *ad hoc*) for important discussion, spread of information, sharing of experiences and coordination of activities. Through this coordinated effort, created by decisions and financing, it has been possible to contain the fruit fly in the North guaranteeing the freedom from the pest in the South and allowing for the export of banana to South Africa to continue. Not only this, but this coordinated effort has also provided the necessary research to develop and spread information on how to best control the pest and guarantee financing for the primary actions.

# 6. The Current Status of the Invasive Fruit Fly Infestation in Mozambique

## 6.1. Occurrence and Distribution of the Invasive Fruit Fly in Mozambique

Of the results obtained in traps from across the country, it is possible to determine that the invasive fruit fly, in April of 2012, occurred in every province in the North of the country. Thus in the 9 years since its first detection in Cuamba, Niassa, this pest was able to disperse South all the way to the Save River.

## 6.2. Population Density of the Invasive Fruit Fly in Mozambique

In 372 fruit-fly traps placed throughout the country from 2010 to 2011, a total of 30 species of fruit flies was recorded belonging to the genera *Bactrocera, Ceratitis, Dacus, Capparimyia Carpopthoromyia, Celidodacus, Clinotaenia, Ocnerioxa* and *Perilampsis.* The species *B. invadens* was the most abundant amounting to approximately 96% of specimens captured (Cugala, 2011).

The average number of adult *B. invadens* (mainly male) caught per day, per trap varied by region. It was highest in Cabo Delgado where 564 specimens were captured per day, per trap. The region with the lowest average was the province of Zambezia which recorded only 0.2 specimens per day, per trap (Table 2.). As of July of 2011, no detection of *B. Invadens* has been recorded in the South of the country (Cugala, 2011).

**Table 2. Average Number of Adult *B. invadens* Captured per Trap, per Day, per Province**

| Province/Locals Sampled | Number of Adult *B.* Invadens Captured | Average Number of Adult *B.Iinvadens* Captured per Trap, per Day |
|---|---|---|
| Cabo Delgado-Niuge, Miese | 9,018 | 564 |
| Nampula-Namapa | 136 | 68 |
| Niassa- Cuamba | 150 | 30 |
| Sofala-Muxungue | 78 | 4 |
| Tete-Zóbue | 186 | 2 |
| Manica-Inchope | 50 | 1 |
| Zambezia-Quelimane | 2 | 0.02 |

Source: Cugala (2011)

In Tanzania, over 600 *B. invadens* specimens were captured per trap, per day in mango fruit farms(Mwatawala *et al.,* 2006) and in Senegal over 1,000 specimens of *B. invadens* were observed in traps after only 1 day of exposure(Ndiaye *et al*., 2008).

## 6.3. Incidence and Severity of the Attack of the Invasive Fruit Fly in Mozambique

Results of a study done by José *et al*. (2012) in Cabo Delgado, during the 2011/12 campaign, show that in Miese(an area with high *B. invadens* population density) the species *Bactrocera invadens* had the most active males in the area (numbering 3,265 individual flies).

This staggering number correlated to an abundance of *B. invadens* account for 97% of all males, followed by other species of the *Ceratitis* genus.

Of the host fruits examined in this study (guava, annona, peanut, pomegranate) mango was the host fruit which presented the highest number of pupas per fruit, suggesting that in the studied area mango was a preferred host(José *et al*., 2012). The percent of mangos damaged by *B. invadens* varied from 55% to 90% in the end of the mango producing season, which signals an average damage of 72.5%. The average number of pupas recorded per fruit and per individual kilo of mango were 13.5 and 41.8, respectively. Mwatawala *et al*. (2009 and 2006), in Tanzania, reported averages of 175.8 adult *B. invadens* per kilo of mango and in Kenya, Rwomushana *et al.* (2008) observed an average of 104.3 adult *B. invadens*/kg of mango.

The occurrence of *Bactrocera invadens* in high densities, in the study areas, and a reduced number of specimens of the genus *Ceratitis* (supported by data obtained pre-invasion) indicates that the invasive species is dominating the native species in the areas it has dispersed to. The dominance of *B. invadens,* in terms of abundance and number of adult active males in relation to native species, corroborates the observations of Ekesi *et al.* (2009) and Mwatawala *et al*. (2009) which argued that while the fruit fly poses a serious threat to agriculture it also has a large impact on the fauna of native fruit fly species (ecological impact). In Kenya as well as in Tanzania, these authors observed that the population of the *B. invadens* was larger in various species of host fruits and thus concluded that *B. invadens* numerically dominated the native species of *Ceratitis* constituting 98% and 88% of specimens captured in traps and mangos respectively. This phenomenon is called *competitive displacement* and it occurs due to *B. invadens* elevated reproductive capacity (which allows for quick population growth), its improved mobility (which grants it more capacity to arrive first to food sources) and the fact it has been introduced into an environment without its natural predators (Duyck *et al*., 2007).

### 6.4. Methods of Control Used Against the Invasive Fruit- Fly in Mozambique

The fruit fly management strategies, have as their objective the reduction of the population density of fruit flies and the reduction of production and revenue losses caused by the fruit fly infestation (Ekesi and Billah, 2007). In Miese, Cabo Delgado (Niuje), from December 2010 until now integrated fruit fly management strategies have been implemented. Such strategies include biological control (release of parasitoids and entomopathenogenic fungi) and the application of toxic bait (Mazoferm) (Cugala, 2011). In Manica, since 2011, Vanduzi's company, the Ganel company and some private producers of mango have been applying the male annihilation technique, toxic baits and improving sanitation of fruit farms (focusing primarily on the collection of fallen fruit).

The cultural control includes the collection and destruction of infected fruits and fallen fruit around the fruit trees. In all the examined locations, the fruit is collected at least once per week and buried in the ground with a depth of over 80 cm or kept in an *augmentorium.* The *augmentorium* has a tent-like structure which sequesters or captures the fruit flies which emerge from the fruit but also, allows for the escape of parasitoids through a fine net(which is yellow) at the top of the tent. As such, it serves a dual purpose: cleaning the fruit farm and protecting the natural enemies of the fruit fly (Ekesi and Billah, 2007).

In August of 2011 the inoculation using the entomopathenogenic fungi *Metarhizium Anisopliae* and the application of bait (BAT) and fumigation commenced. The toxic bait made with Mazoferm and NULURE were applied in Miese, Koma-Koma 2. Both the Mazoferm and NULURE were imported from ICIPE-Kenya, and prepared (mixed with insecticide Spinosad and water) before application. The mixture (Mazoferm and Spinosad) was placed in the traps which were then installed in host fruit trees (focusing on trees with already mature mango and guava). The traps are then inspected weekly and the mixture replaced, NULURE is applied in a 1 $m^2$ area of foliage, 2-3 meters off the ground (Cugala, 2011).

Biological control is being implemented in Cabo Delgado, with financial backing from the World Bank and FAO as well as collaboration with ICIPE-Kenya. Initially, approximately 20,000 parasitoid pupas (*Fopius Arisanus)* for the eggs of *B. Invadens* were imported from ICIPE. At the emergence of the parasitoids, on the 23rd of August 2010, 6,000 parasitoids were released in Miese-Niuje, district of Pemba, Cabo Delgado. On the 25th of September of the same year, more than 2,000 parasitoids were released in the same location and a final release was done in November of the same year. The growth and impact of this colony is still in evaluation stages (Cugala, 2011). In Kenya, Tanzania, Benin and Uganda *Fopius Arisanus* has shown promise as an agent of biological control for *B. Invadens.* In Kenya it is estimated that there has been a reduction in the population of *B. Invadens* by 70% in fields where *Fopius Arisanus* has been released (Ekesi, no date).

Preliminary results of the treatments applied in Miese show the population density of fruit flies captured in traps(fruit flies caught per trap, per day) decreased in areas treated in relation to areas not treated(Cugala, 2011).

### 6.5. Forecast for the Dispersion of the Invasive Fruit Fly in the Southern Part of the Country

According to De Meyer *et al.* (2010) *B. Invadens* prefers warm and humid climates with high annual precipitation. Due to this the zones most suited to *B. invadens* are equatorial climates (minimum temperature ≥18°C), particularly in humid equatorial areas (AF) and monsoon areas (Am) as described by the climate classification of Köppen-Geiger. The same authors also state that the dry winter (Aw) of equatorial savannahs also provides a highly adequate climate for the species. On top of this, *B. invadens* has also been found in zones with the climate type Csa (dry winters with minimum winter temperatures below 18° C) (Mwatawala *et al* 2006).

Based on the information of De Meyer *et al*. two models were developed (GARP and Mexent) to predict the potential distribution of the invasive fruit fly in Southern Africa and Madagascar (Figure 6). Both the models predict that the invasive fruit fly could establish itself in the Southern region of the country, with a higher probability of infestation in the coastal areas of the provinces of Inhambane, Gaza and Maputo.

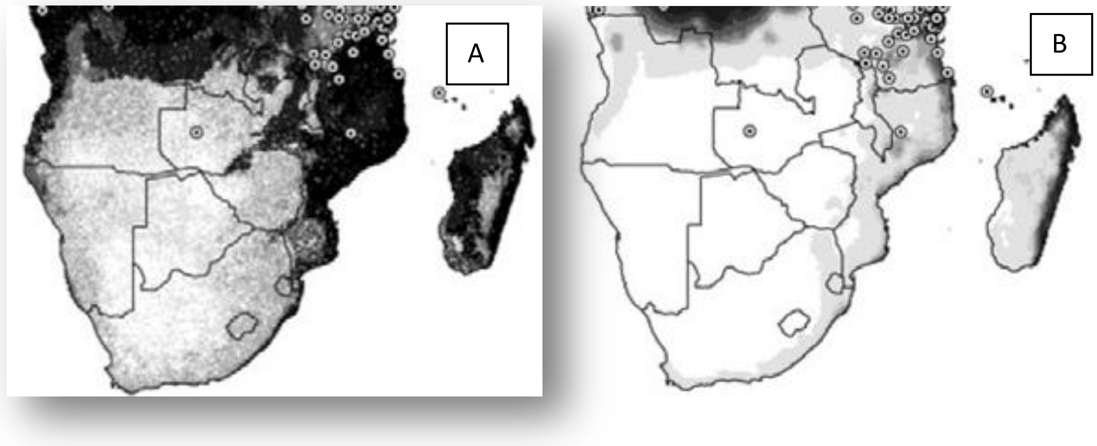


**Figure 4. Prediction of the Distribution of *Bactrocera invadens* in Southern Africa and Madagascar using the GARP (A) and Maxent (B) Models**. The lighter zones are where a lack of the species is predicted while the darker zones are predicted for higher occurrence (Source: Cassidy, no date)

# 7. Impact of the Invasive Fruit Fly in the Infested Area

## 7.1. Characteristics of Producers Interviewed

A total of 12 producers responded to the questionnaire corresponding to 100% of the total number of producers of banana and mango listed by DSV in the provinces of Cabo Delgado, Nampula and Manica. A list of producers included in the census is detailed in annex 5.

The banana producers interviewed are on average 4 years old, and have an average plantation size of 356 ha and approximately 33 tons/ha in production (Table 3). The mango plantations have dimensions varying from 1 to 74 ha and have been running on average for 11 years. In these plantations there is an average product of approximately 12 tons/ha (Table 3).

**Table 3.** Descriptive statistics for the characterization of producers which responded to the survey (infested region)

| Cultivation | Characteristics | N$^o$. of Observations | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Banana | Area (ha) | 5 | 335.8 | 598.14 | 6.0 | 1,400 |
| | Production (ton/ha) | 5 | 32.7 | 24.2 | 3.0 | 60.0 |
| | Number of Trees | 5 | 730,441 | 1,379,973 | 12,500 | 2,800,000 |
| | Age of Fruit Farms(years) | 5 | 4.0 | 2.0 | 2.0 | 6.0 |
| Mango | Area (ha) | 8 | 20.6 | 23.7 | 1.0 | 74.0 |
| | Production (ton/ha) | 8 | 11.8 | 9.3 | 2.0 | 25.0 |
| | Number of Trees | 8 | 12,532.0 | 18,074.5 | 250.0 | 48,000.0 |
| | Age of Fruit Farms(years) | 8 | 11.0 | 10.6 | 2.0 | 25.0 |

Source: Data collected by authors

The produce from these business has a destination of both exporting to foreign markets as well as selling to domestic markets. Of the 12 producers interviewed, 48% sell fruit exclusively to domestic markets (national), while the remaining 58% produce both mango and banana with goals of exporting to foreign markets. However the remaining 58% also sell part of their produce to local markets.

All the producers interviewed confirmed knowledge of the invasive fruit fly and the pest was present in all but 3 of the plantations amounting to 75% of producers inquired.

## 7.2. Losses in Production Caused by the Fruit Fly in the Commercial Fruit Sector (Mango and Banana)

It is estimated that the amount of banana and mango produced in the commercial sectors of the Northern and Central regions of the country(infested areas) could have reached, in 2011, 2,600 and 23,000 tons, respectively, according to information provided by producers.

Approximately 90% of the 12 producers who responded to the inquiry, of both cultivations, confirmed that the fruit fly (*Bactrocera invadens)* does not cause significant damage to their fields. Only 10% of producers complained about problems with the pest, particularly in the cultivation of mango.

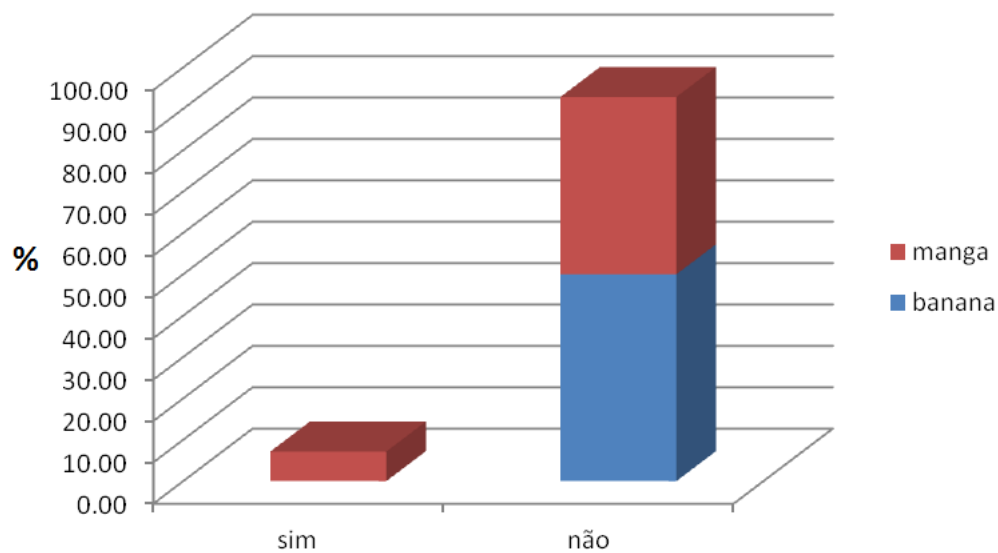


**Figure 5.** Percentage of Banana and Mango Producers Affirmations of the Loss of Production Caused by *Bactrocera Invadens*

For the case of the cultivation of banana, according to producers, the collection of the fruit is done while the fruit is still in the green stage. In this physiological stage the banana does not constitute a suitable host for the invasive fruit fly (Cugala *et al.*, 2012). Due to this the fruit fly is not a large cause of loss of production in banana cultivation. Thus the losses in production due to the invasive fruit fly were considered negligible.

In the case of mango cultivations, data obtained by José *et al.* (2012) indicates losses in production caused by the invasive fruit fly in the amount of 30% for the province of Cabo Delgado and 23% for the Central region of the country(due to the implementation of control methods in this part of the country). Studies evaluating the efficacy of the control methods of other countries report a reduction in damage caused by the fruit fly in fruit by 17% in Senegal and 30% in Kenya with the use of toxic baits (attractant GF120 mixed with insecticide), mounting of traps based on methyl Eugenol mixed with malatião (Ekesi, no date), and the collection of fallen fruit. These same methods also have been implemented by some producers in the Central region of Mozambique. Thus, to estimate the value of this loss of production due to the invasive fruit fly a 23% loss in production would equate to roughly 828 tons of mango per year. At an average price of 15Mt/kg the monetary losses from the production of mango are estimated at 12.4 million Mt/year.

### 7.3. Loss of Markets and Value of Exports

With the occurrence of the fruit fly in the North of Mozambique, one of the measures were taken by the government was to restrict the movement of fruit from the Northern region to the Southern region of the country. Simultaneously the South African and Zimbabwean governments also prohibited the entry of fruit from the Northern region of Mozambique. These facts have had an impact on the markets for these fruits and their value as exports.

Table 4 illustrates the comparative table for the destination of fruit in the scenarios before and after the occurrence of the invasive fruit fly in the Northern and Central regions for the producers interviewed. It can be clearly seen in this table that the mango producers have partially lost the South African market while the banana producers have completely lost their Zimbabwe and Maputo markets.

**Table 4. Primary Commercial Destinations (National and International) for Banana and Mango Before and After the Introduction of the Invasive Fruit Fly in the Infested Zone.**

| Cultivation | Destination of Produce | |
|---|---|---|
| | Before the Introduction of the Fruit Fly(2009) | After the Introduction of the Fruit Fly (2011) |
| Banana (Manica) | Zimbabwe, Zambia, Maputo and Chimoio | Zambia, Tete, Beira and Chimoio |
| Banana (Nacala) | Zimbabwe | Middle East, European Union, Iran |
| Mango | RSA | Middle East, Singapore, RSA (conditionally), Chimoio, Beira and Tete |

Source: data collected by authors and DSV

The South African market, before the introduction of the fruit fly, was positioned as the main commercial market for producers of mango in Manica, particularly the business GANEL. With the introduction of the fruit fly, and import restrictions imposed by the South African government, this business could only continue exporting mango under condition of product certification, thus in lesser quantities. Due to this the average quantity of mango exported by this company to South Africa has decreased from 350 to 115 tons/year. To minimize the negative effects of this situation one of the alternatives found by GANEL was to find new international markets (100 tons to the Middle East and Singapore) for mango. However, the quantities of mango exported to these new markets were not enough to cover the losses in the South African markets, which has seen a 38% decrease in exports.

Before the introduction of the fruit fly, the Maputo market was the primary destination for banana produced by the Association of Banana Producers of Macate, located in the district of Gondola in the Manica province. This association currently is made up of approximately 80 members who own plots with an average area of roughly 4 ha and produce circa 3 tons/ha. This equates to roughly 960 tons of banana, 70% of which more or less (670 tons) was commercialized in the markets of Maputo. With the loss of this market, due to the restricted movement of fruit from the Northern region of the country to the South, the producers of this association have been “obligated” to sell the excess produce on the local markets(circa 600tonnes/year) at reduced prices. It is because of this that these producers observe significant losses of production due to the local markets of Gondola and Chimoio not having enough to demand to absorb the banana produced locally. It is estimated that approximately 70 tons/year, in 2011, have gone un-commercialized (10% of production) equating to 1.75 million Mt/year. Add to this the average price of banana in the Chimoio market is lower than that of the Maputo market (6 and 25 Mt/kg respectively), and additional 11.4 million Mt/year in losses of banana sales have been estimated substantially affecting the livelihood of producers and their families in Macate.

The major international markets for banana produced in Manica, prior to the introduction of the invasive fruit fly, were Zambia and Zimbabwe. These two countries alone accounted for 60% of all banana exports for the province. After the introduction of the fruit fly, a complete loss of the Zimbabwean market and a partial loss of the Zambian market occurred (Table 5). Due to the loss of these international markets producers have been forced to sell their produce only in the local markets at a lower price (around 6 Mt/kg instead of the 7Mt/kg in the international markets). The loss of these international markets has caused an increase in the supply of commercial banana for the Central region markets resulting in a surplus.

In 2009 and 2010 the Zimbabwean market was one of the most important sectors for commercialization of bananas produced in Nampula by the company Matanuska. With the current events, in 2010 and 2011 new international markets were added for the commercialization of banana for Matanuska. Due to confidentiality reasons, Matanuska did not report the names of the markets where the banana is being sold, nor the losses of exports caused by the import restrictions imposed by the South African market. For this reason, for the case of banana farms, it was not possible to estimate the volume of exports lost. Another factor limiting the estimation of the volume of production lost in exports is that other producers failed to document the volumes of banana being produced per season.

According to Cugala (2011), just in 2008, due to the restrictions on exports following the detection of the invasive fruit fly in the province of Manica, the Vanduzi Company lost in just a month roughly 1.5 million dollars (42 million Mt).

According to the presentation done in May, by the president of Fruticentro during the launch of the AgriFUTURO project, a banana producer lost approximately 300 tons with the loss of the Zimbabwean market (equating to 80,000USD). Yet in this presentation, a loss is referenced with the value of 450 thousand dollars in the cultivation of mango between 2009 and 2010. The divergence between the values found by the authors and those cited in the presentation could be explained by the fact that some large companies refused to answer the quatinnaires completely on the grounds of confidentiality and others do not keeping proper records about volumes of production.

## 7.4. Losses in Food Security

It was not possible in this study to determine the losses in food security. According to the defined methodology of the study the losses in food security should have been estimated comparing the availability of the fruit on the markets before and after the introduction of the invasive fruit fly. However this information could not be obtained because once the 79 merchants inquired in the various markets none had heard of or knew of the invasive fruit fly and had not noticed any difference in the availability of fruit in the market.

Most of the banana vendors interviewed in the Northern region commented that banana is available on the market for 4 or more months (Table 5). For mango the same vendors confirmed it was only available for 2 or 3 months per year (Table 6). In the commercial fruit markets in the Southern region it was confirmed by all 15 vendors interviewed that banana is available year-round and mango is available from November to March.

**Table 4. Percentage of Vendors of Banana in the Three Provinces in the Infested Zone in Relation to Reports of Fruit Availability in Local Markets**

| Number of Months Per Year | Percentage of Vendors | | |
|---|---|---|---|
| | Cabo Delgado | Manica | Nampula |
| 2 | 5.26 | 0.00 | 0.00 |
| 3 | 5.26 | 0.00 | 30.00 |
| 4 | **47.37** | 0.00 | 0.00 |
| 5 | 15.79 | 10.00 | 0.00 |
| 6 | 15.79 | 0.00 | 0.00 |
| 7 | 0.00 | 0.00 | 10.00 |
| 12 | 10.53 | **90.00** | **60.00** |

Source: Data collected by authors

**Table 5. Percentage of Vendors of Mango in the Three Provinces in the Infested Zone in Relation to Reports of Fruit Availability in Local Markets**

| Number of Months Per Year | Percentage of Vendors | | |
|---|---|---|---|
| | Cabo Delgado | Manica | Nampula |
| 2 months | 18.18 | 20.00 | **100.00** |
| 3 months | **72.73** | **80.00** | 0.00 |
| 4 months | 9.09 | 0.00 | 0.00 |

Source: Data collected by authors

With this, regarding the cultivation of banana, we can see that both the infested and non-infested zones have a secure supply of banana 12 months of the year in local markets. In this case rural families consume this fruit year round and secure some nutritional necessities in terms of vitamins. In the infested zone, approximately 72% of the vendors confirm that mango is available only 3 months of the year. This demonstrates an occurrence of the fruit fly exists as there is a reduced period of availability and consumption for mango in the infested area as opposed to the non-infested one(November to March - 5 months). Due to this, rural families in the infested zone have less diversification in their fruit consumption (which could have dietary consequences) than the families in the non-infested area.

## 7.5. Increases in the Production Costs for Producers

In general, the producers of banana in the Northern region do not utilize any methods of fruit fly management and so the occurrence of the pest has not increased production costs. Only certain mango producers have actually implemented these anti-fruit fly measures in their fruit farms. Of the total 12 producers interviewed, 27.3% have used integrated fruit fly control and only 18.2% apply chemical control although to combat other pests (Table 7).

**Table 6. Percentage of Farmers by Method of Control Implemented and their Respective Annual Costs of Control in Infested Zones**

| Method of Control | N$^{o}$ of Producers | % of Producers | Costs of Control (Meticais/ha) | |
|---|---|---|---|---|
| | | | Mango | Banana |
| Biological | 1 | 8.3 | 0 | 0 |
| Cultural | 2 | 16.7 | 0 | 0 |
| Integrated | 3 | 25.0 | 12 990 | 0 |
| Chemical | 2 | 16.7 | 24 000 | 0 |
| No Control Method | 4 | 33.3 | 0 | 0 |

Source: Data collected by authors

The information gathered by farmers it was concluded that the integrated pest management, despite being costly, was effective in the fight against the pest. This method is used by the company GANEL, which currently is the company representative of the fight against fruit flies in the province of Manica, a company which has certified the absence of the fruit fly in its farms (Figure 8). According to GANEL technicians the integrated control consists of cleaning the fruit farms and fumigating every 6 weeks using the “baits spray application technique” (BAT). This method of fruit fly management, even with the presence of the fruit fly in the Manica province, has allowed this company to continue exporting mango to South Africa for processing in lesser amounts.

For the case of biological and cultural control methods between the 12 producers interviewed only 3 solely utilize these methods, despite their lack of costs. The biological control referred to here is that of releasing a natural enemy of the fruit fly and has been utilized in a farm (Miese-Niuje) in the province of Cabo Delgado, in the context of the evaluating study on the efficacy of this method performed in 2010/11 by DSV and FAEF.


**Figure 6. Plaque certifying the company GANEL (ex EAM)**

## 7.6. Costs of Control Operations Implemented by MINAG/FAEF

After the introduction of *B. invadens* the Ministry of Agriculture; through the DSV, the Faculty of Agronomy and Forestry, the private sector and other collaborating partners have developed various actions for the containment of the invasive fruit fly in Mozambique. On this scope, financial aid was requested from the World Bank and FAO to establish a monitoring program in the different regions at risk in the country. This aid had also as a goal the construction and establishment of a laboratory in the Northern region of the country in the province of Cabo Delgado as well as the release of a natural enemy of the fruit fly as a method of biological control.

Table 8 summarizes the costs of the different actions undertaken by MINAG/FAEF as well as the amounts financed by FAO and the World Bank. The estimate for the costs of monitoring the pest were made based on the methodology presented in annex 3 and the details of the results of these costs are described in annex 7. The amount of costs due to the quarantine measures presented here correspond to the annual salary payment of 2 technicians located at posts bordering the Save River with a view of controlling fruit movement. Other costs that could have been accounted for would be the publishing of leaflets, training programs and the divulgation of information about the measures, which could not be calculated due to lack of information.

**Table 7. Costs of Operations of Control Triggered by MINAG/FAEF**

| Operations Triggered | Costs of Operations (millions of MT) | Financiers | Value of Project (millions of MT) |
|---|---|---|---|
| Quarantine Measures | 0.48 | FAO | 8.4 |
| Pest Monitoring | 8.9 | MINAG | |
| Laboratory Construction | No information | World Bank | 2.8 |
| Release of Natural Enemy | No information | | |
| **Total** | **9.38** | | **11.2** |

Source: Data collected by authors

## 7.7. Jobs

The 12 producers interviewed had on average 18 employees before the introduction of the invasive fruit fly and after the introduction of the fly these companies only employ on average 15 workers. (Table 9).

**Table 8. Average Number of Effective Workers per Farm in Infested Areas**

| Cultivation | N° of Producers | Average Number of Workers per Farm | |
|---|---|---|---|
| | | Pre Fruit Fly Introduction | Post Fruit Fly Introduction |
| Banana | 4 | 18 a | 15 a |
| Mango | 8 | 17 a | 15 a |

Pairs with same letter do not differ significantly based on the T-Test with 5% significance
Source: Data collected by authors

The employment profile for agricultural activity in Mozambique is characterized primarily by seasonal workers. By comparing the numbers of seasonal workers in the periods before and after the introduction of the fruit fly, a significant reduction in the number of seasonal workers(primarily in banana farms) can be seen (Table 10). This reduction in the number of seasonal workers is explained by the diminishing export of fruit as prior to the arrival of the fruit fly the demand for Mozambican fruit in the international market was greater. Banana producers in particular contracted many seasonal workers to deal with the cutting of clusters and their respective bagging. With the presence of the fruit fly, a large amount of fruit is sold at the door of the farm and in other local markets, usually in lesser quantities, and for this the producers use their effective work force.

This is just one example of the negative impact of the occurrence of the fruit fly contributing to the substantial reduction in jobs which effects, on a large scale, the income of rural families and may have consequences on food security.

**Table 9**. **Average Number of Seasonal Workers per Farm in Infested Areas**

| Cultivation | N° of Producers | Period Relative to the Introduction of the Fruit Fly | |
|---|---|---|---|
| | | Pre Fruit Fly Introduction | Post Fruit Fly Introduction |
| Banana | 4 | 129 a | 74 b |
| Mango | 8 | 25 a | 22 a |

Pairs with same letter do not differ significantly based on the T-Test with 5% significance
Source: Data collected by authors

## 7.8. Investments not realized

Due to the occurrence of the fruit fly in the Central and Northern regions of the country, many producers have had their expansion plans for cultivation areas cancelled. Table 11 shows the planned investments not realized and/or cancelled such as, the plans for farms in terms of area and volume of production projected for the years of 2012 and 2015.

**Table 10**. **Planned Production of Fruit farms and Investment not realized in the Infested Area**

| Culture | Production Plan | | | | Investment not Realized/Cancelled | |
|---|---|---|---|---|---|---|
| | Area (hectares) | | Production (tons) | | Hectares | Value (millions of MT) |
| | 2012 | 2015 | 2012 | 2015 | 2012 a 2015 | |
| Banana | 356 | 846 | 10,800 | 39,800 | 460 | 128.8 |
| Mango | 200 | 292 | 1,740 | 3,328 | | |
| Citrines | 50 | 650 | 0 | 13,000 | 650 | 182 |
| Avocado | 50 | 144 | 0 | 574 | | |
| Litchi | 136 | 186 | 281 | 1,055 | | |
| **Total** | **792** | **2,118** | **12,821** | **57,757** | **1,110** | **310.8** |

Source: Presentation done in May 2012 at the workshop about the monitoring of the fruit fly

With the occurrence of the fruit fly the production plans of fruit farms presented in the above table was comprised in the following ways:

- Investments postponed and potentially cancelled, this is, 460 hectares of orchards, approximately 4.6 million USD of investment (roughly 128.8 million Mt), more than 400 jobs and the loss of potential and continuing revenue of 7.5 million USD. These fruit farms and plantations would be established by the end of 2012.

- Plans for citrine plantations were potentially suspended. Plans involving: 650 hectares of citrine, 6.5 million USD of investments(roughly 182 million Mt), 550 permanent jobs and estimated annual revenue equating to 10 million USD projected before 2015 are currently suspended.

## 7.9. Summary of the Impact of the Invasive Fruit Fly in the Northern and Central Regions of Mozambique

Table 12 presents a framed summary of the primary impact indicators of the invasive fruit fly in the infested area. For some indicators, such as food security and jobs it was not possible to quantify and are of a qualitative nature. The primary impact on jobs was seen in the decrease in number of seasonal workers, particularly in the cultivation of banana. The calculation for the value of losses of production was obtained by comparing the amount of production obtained before and after the introduction of the fruit fly. The increase of costs of production was done only for the company GANEL, as it is the only one who efficiently manages the fruit fly. The estimate of the increase of costs was obtained by multiplying the cost per hectare by the total area of production (74 ha) of the company.

**Table 11**. **Summary of the Estimated Values of Indicators of Impact of the Fruit Fly in Infested Areas (Banana and Mango)**

| Impact Indicator | Value (millions of Mt/year) |
|---|---|
| Production Losses | 12.4 |
| Loss of National Markets and Lowering of Prices (Banana – Macate) | 13.2 |
| Loss of Exports (only mango for GANEL and Vanduzi's company) | 44.4 |
| Loss of Food Security | Reduction in the period of consumption of manga by rural families. |
| Increase in Production Costs for Companies (In the case of GANEL) | 0.96 |
| Costs of Control Operations by MINAG | 9.38 |
| Jobs | Reduction in the number of seasonal workers. |
| Investments not Realized | 310.8 |
| **Total** | **391.14** |

# 8. Potential Impact of the Infestation of the Invasive Fruit Fly in the Currently Unaffected Southern Region of Mozambique

## 8.1. Characteristics of Producers Interviewed

A total of 12 producers of banana (10) and mango (2) responded to questionnaires in the non-infested areas in the provinces of Maputo and Gaza. The list of producers included in the census is detailed in annex 5.

The fruit farms of the 10 banana producers interviewed in the zone had an average age of 4.3 years, with an average cultivated area of 122 ha producing approximately 25 tons/ha(Table 13). The two mango farms that responded to the questionnaire in this area have dimensions that vary from 1.5 to 6 ha and an average age of 7.5 years. These farms on average produce 10.5 tons/ha (Table 13).

**Table 12. Descriptive Statistics for the Characterization of Producers who responded to survey in the Non-Infested Area**

| Cultivation | Characteristics | N$^{o}$. of Observations | Average | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Banana | Area (ha) | 10 | 122 | 170.5 | 1.5 | 530 |
| | Production (tons/ha) | 8 | 24.9 | 25.7 | 2 | 60 |
| | Number of Trees | 3 | 382,833 | 213,762 | 220,000 | 624,900 |
| | Age of Farm (years) | 9 | 4.3 | 2.5 | 1 | 10 |
| Mango | Area (ha) | 2 | 3.75 | 3.19 | 1.5 | 6 |
| | Production (tons/ha) | 2 | 10.5 | 12.02 | 2 | 19 |
| | Number of Trees | 2 | 272.5 | 243.95 | 100 | 445 |
| | Age of Farm (years) | 2 | 7.5 | 0.7 | 7 | 8 |

Source: Data collected by authors

## 8.2. Impact on the Production and Export of Banana

Fruit production, specifically banana production, is a major source of income for many producers in the Southern region of the country currently unaffected by the fruit fly. The majority of the banana produced in the Southern region of the country in the districts of Boane, Moamba and Manhica is destined to the South African market, while the remainder is used to fill the demand in the city of Maputo. According to data provided by DSV it is estimated that in the last year alone approximately 53,754 tons of banana was exported to the South African market. This amount of banana exported represents 85% of banana produced in the Southern region of the country (A. Gomes, personal communication). With respect to the amount of banana commercialized in the domestic market it is estimated that in 2011 slightly less than 9,500 tons of banana were commercialized. In terms of revenue the cultivation of banana generates approximately 740 million meticals of which 645 million meticals come from exports (Table 14).

**Table 13. Value of Production (Millions of Mt) in Domestic and Foreign Markets in the Non-Infested Area**

| Cultivation | N° of Producers | Value of Production in Exports ($x10^6$ Mt) | Value of Production in Domestic Markets ($x10^6$ Mt) | Value of Total Production ($x10^6$ Mt) |
|---|---|---|---|---|
| Banana | 10 | 645 | 95 | 740 |
| Mango | 2 | 0 | 0.38 | 0.38 |
| **Total** | | **645** | **95.38** | **740.38** |

Source: Data collected by authors

In numeric terms banana farms are estimated at creating approximately 4250 jobs (Table 15). The large number of workers employed in banana farms shows how important this fruit industry is in a socio-economic sense for the Southern region of the country.

**Table 14. Total Number of Effective Employees and Seasonal Workers in Farms in Non-Infested Area**

| Cultivation | N° of Producers | Effective Employees | Seasonal Workers |
|---|---|---|---|
| Banana | 10 | 4,241 | 910 |
| Mango | 2 | 8 | 30 |
| **Total** | | **4,249** | **940** |

Source: Data collected by authors

Should the fruit fly invade the Southern region of the country, South Africa would prohibit the import of all banana coming from Mozambique. This measure would have such a huge negative impact as to not only reduce the value of exports by an estimated 23 million USD annually but also would make many companies unable to continue to function resulting the loss of approximately 5,200 jobs.

## 9. Cost-Benefit Analysis of Maintaining the Southern Region of the Country Free of Infestation

With the occurrence of the fruit-fly in the northern and central regions of the country, there is a strong threat of invasion of the pest into the region south of the Save River. Trying to avoid this from happening it was set a monitoring system as well as some quarantine measures to ensure that the south region is still currently declared free of the fruit-fly. The declaration of the free zone is a condition determined by South Africa, following international laws, to authorize imports of bananas and other fruits and vegetables which could be hosting the invasive fruit-fly produced in this region of Mozambique.

A cost-benefit analysis was used to determine the economic advantage of maintaining the south region of Mozambique free from the invasive fruit-fly. The benefits included: exports value and sales of bananas in the domestic markets that are not lost, jobs not lost and company costs to control the fruit-fly which are not incurred in the pest free region. Costs included: quarantine measures, monitoring of the pest and losses of producers in infested regions which due to restrictions imposed by the quarantine measures lost their markets in the south region of the country.

The value of production and exports not lost were obtained through the Table 14. The estimation of the annual value of jobs was calculated using the monthly minimum wage of 2,300 MT for a full-time worker and 10% of these for sazonal workers. Other benefits that could have been included in the labor cost are social benefits. Because these benefits have a quality characteristic they were not included in the analysis. The estimation of control costs of the fruit-fly not needed were obtained using as a reference the control cost per hectare from the Ganel company (Table 12) and multiplying it by the total area with banana, mangoes and other fruits (approximately 2,400 ha) used by companies in the south region.

The value of the quarantine measures presented is derived from the annual salary paid to 2 technicians at the border post of Save River aiming at controlling the movement of fruit. Other possible costs that could have been included are leaflets publication, training and dissemination, but were not included due to lack of data. The estimation of monitoring costs followed the methodology presented in Annex 3 and the details of the results are included in Annex 7. The costs of lost sales by being banned in the southern region, in particular in the Maputo market, by the producers in the infested regions were calculated using the volume of production that were produced and exported to the southern region before the occurrence of the fruit-fly. The costs of lost sales due to restriction on exports when the fruit-fly was detected in Mozambique for the first time were obtained from Cugala 2011. As per this author, some US $2 million were lost in 2008 in the provinces of Maputo and Manica.

The CBA estimate that the benefits resulting from this measure are larger than the costs incurred (Table 15). The ratio of benefits to cost obtained is 24.35 and it was concluded that it was economically advantageous to continue maintaining the southern region free of the pest.

**Table 155.** Results of the cost benefit analysis of maintaining the southern region free of the invasive fruit-fly

| Indicator | Value (million of meticais/year) |
|---|---|
| **Benefits** | |
| Production value (local market) not lost | 95.38 |
| Non-lost number of jobs | 119.40 |
| Control cost not needed by companies | 30.96 |
| Exports not lost | 645.00 |
| *Total Benefits* | ***890.74*** |
| **Costs** | |
| Monitoring | 8.90 |
| Quarantine measures | 0.48 |
| Lost exports due to exports restrictions imposed when the fruit-fly was detected for the first time | 14.0 |
| Loss of producers in the infested regions for not being able to sell their produce in Maputo | 13.2 |
| *Total Costs* | ***36.58*** |
| **Ratio BC** | **24.35** |

Source: Data collected by the authors

The suspension/non-use of measures to protect the southern region free of the pest would imply an invasion of the invasive fruit-fly and the main impact would include the loss of access to the South African market for exports of banana, an estimated loss of about 645 million meticais and the loss of jobs for over 5,000 workers.

## 10. Main findings

The main findings of this study are:

1. The **invasive fruit-fly is a large threat to the fruit production of Mozambique**, as the level of direct and indirect losses affect a great number of fruit crops, in particular mangoes, as well as vegetables.

2. The **fruit production is an important source of revenues from exports and a job creation** in the country and there are plans for growing and new investments in the sector.

3. The country has already **lost** more than **US $14 million in the infested regions** due to the fruit-fly and in particular due to:
   i. Production loss of the order of US $443,000;
   ii. Loss of markets and exports of US $ 2 million;
   iii. Increased production costs of the companies by at least US $500/ha;
   iv. Operation costs of control by MINAG of at least US $350,000;
   v. Planned investment that was never implemented in the order of US $11 million, which curtailed the planned growth of production and exports of fruits with an estimated potential revenue loss of US $17.5 million per year.
   vi. Losses (not quantified in this study) of food security for reduction of the period of consumption of mangoes by the rural families;
   vii. Reduction of the number of seasonal workers by companies producing fruit.

4. There is **a great probability that the invasive fruit-fly may disperse to the southern region** of the country where conditions to breed exist.

5. **If the fruit-fly invades the south of the country** the export market of bananas to South Africa **will be lost**, which represents **US $23 million per year and some 5,000 jobs**.

6. **There are possibilities to control the fruit-fly** in the infested regions (Northern and Central) of Mozambique which allow to reduce the loss of production. However, these control measures **will not be sufficient to eradicate the invasive fruit-fly** (as the pest is already amply spread), **to declare the entire country free of the pest** and therefore regain access to the export markets. Thus the **value of exports for the countries where the fruit-fly does not occur will always be a loss**. In addition, these measures would imply an **increase of production costs for the companies and for the government**. In Mozambique the companies operating in the infested regions are spending about US $500/ha with the control operations. DSV and its partners have already spent up to this moment at least US $350,000 in control measures of the invasive fruit-fly in the infested regions and in quarantine measures.

7. The **quarantine** (restriction of entry into the country and of movement of hosting, monitoring and eradication of the fruit-fly from the spots immediately as it is detected) **is a control method that allows avoiding the entry and dispersion/spreading of the pest in the country** and therefore **to declare the country of a region free of the pest**. Then it is greatly important to monitor in particular in the regions passive of entry and immediate action to eliminate the detected spots of infestation.

8. The **ratio of cost-benefit** to keep the southern region free of the fruit-fly is estimated to be at least **1:24**. This result proves the advantage of quarantine measures already applied. These measures achieved maintaining the southern region free of the pest since 2007 and up to today.

9. **The quarantine measures and the control actions developed in the country were correct and enabled the containment of the fruit-fly in the northern regions of the country**. However, they were **too slow and did not contain or eradicate the fruit-fly** at the initial spots permitting therefore rapid dispersion/spreading in the northern regions and the existing great risk of spreading into the southern region in the short future.

10. **There is a great probability of occurrence of other fruit fly species** invade the country in the short future. The species *Bactrocera latifrons* that is infesting a great variety of fruits was detected for the first time in Tanzania in 2006. The experience gathered with the invasive fruit-fly resulted in an increased national capacity to deal with similar situations in the future.

## 11. Recommendations

Based on the main findings, this study recommends:

- **Continue and improve the control actions** already initiated in the northern regions of the country. These actions, taking into account experience of other countries, will significantly reduce the population density of the invasive fruit-fly and will also reduce production losses to less than 5%. In addition, the reduction of the population density of the fruit-fly in the northern and central regions will decrease the probability of spreading of the pest to the southern region, enabling a better environment to maintain the southern region free of the pest and keep its current access to export markets.

- **Continue and strengthen the quarantine measures** that have been enabling to declare the southern region free of the pest. It is needed that beyond maintaining and improving the monitoring system based on traps already in implementation, to create capacity and a system of immediate action/response with control actions when detection of any invasive fly occurs. These immediate and spot control actions curtail dispersion/spreading of the pest into other areas and to keep the southern region free.

- **Continue research** on the efficacy and efficiency of the current control methods, on new control methods, on impact on production and agro-ecological impacts. This continued research will improve the recommendations to the producers aiming at reducing production losses both to the commercial and family sectors.

- **Invest and promote the processing of bananas and mangoes locally** to possibility compensate for losses of exports. In the northern regions production losses are great due to lack of access to domestic and foreign markets which will impact negatively the production. Processing the fruit is an alternative to increase the demand for fruits in the domestic market.

- **Find alternative international markets to South Africa** for bananas and mangoes taking into account the existing international restrictions and the potential for green-banana exports for certain countries (the green-banana is not a host of the invasive fruit-fly).

- **Improve organization of the domestic fruit and vegetable sectors**. These sectors have a great potential as a source of export revenues, and a source of raw-materials for the food-processing industry to improve revenues/incomes and food security and nutrition of millions of family sector producers and urban consumers. These sectors are greatly contribute to job creation as it involves a large number of family sector producers of fruits and vegetables that are sold at domestic markets in rural and urban areas as well for auto-consumption. However, this study detected due to lack of information that these sectors are not a priority for intervention and research and there is no agency in MINAG that is in-charge of promoting these sectors. It is prove of this the lack of information on the sectors and the difficulty for timely action and resource mobilization from the government to find a solution to the fruit-fly problem. Recommendations include: (i) increase the allocation of resources to research on the agriculture sector; (ii) create an institution to coordinate and promote the fruit and vegetable sectors as it has been done with the cotton sector; (iii) improve the production of information directed to producers, exporters and investors on these crops and their potential production areas; export markets; plant protection regulation; etc.

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## Annex 1A. Survey to producers of fruit (infested zone)

Date____/_____/2012

Province____________________________ District__________________________

Local __________________________ Interviewer _____________________

1. Identification data

Nome of producer or company _______________________________________________________

2. Fruits produced

| Crop | Area | Number of trees | Orchid age | Yield |
|---|---|---|---|---|
| Banana | | | | |
| Mango | | | | |
| Other (s) | | | | |

3. Was is the destination of your production?

Local market_______ Export ________

4. Market sales

| Crop | Main markets | |
|---|---|---|
| | National | International (exports) |
| Banana | | |
| Mango | | |

**Impact of the fruit-fly *Bactrocera invadens***

5. Have you heard about the fruit-fly *Bactrocera invadens*? Yes _____ No ______

If yes,

6. Do you know the impact and losses that the pest can cause? Yes _____ No _______

If yes, which are those? _______________________________________________________________

________________________________________________________________________

7. Is this pest present in your exploration? Yes ______ No _____

If yes, since when? ______________________________________

8. Which methods of control have you used to combat this pest?

Chemical _______ Biological __________ Cultural _________ Integrated ________

Other (specify) ______________________

9. Description of the control methods (including the material and human resources used)

______________________________________________________________________________

10. What are the costs related to the method (s) of control used?

| Method of combat (mark with an X) | | Costs | | | |
|---|---|---|---|---|---|
| | | Material means | Human | Other | Total |
| Chemical | | | | | |
| Biological | | | | | |
| Cultural | | | | | |
| Integrated | | | | | |
| Other (specify) | | | | | |

11. Are there positive differences in terms of production before and after the introduction of the pest in your exploration? Yes _____ (fill-in the table below) No ______

| Crop | Production (Ton) | | Price (Mt/kg) | |
|---|---|---|---|---|
| | Before | After | Before | After |
| Banana | | | | |
| Mango | | | | |

12. Have you lost access to any market due to the presence of this pest? No _____ Yes _____ (if yes, fill-in the table)

| Crop | Domestic market 1 | | | | Export market 1 | | | |
|---|---|---|---|---|---|---|---|---|
| | Sales before | | Sales after | | Sales before | | Sales after | |
| | Quant. (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) |
| Banana | | | | | | | | |
| Mango | | | | | | | | |

| Crop | Domestic market 2 | | | | Export market 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Sales before | | Sales after | | Sales before | | Sales after | |
| | Quant. (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) | Quant (ton) | Price (MT/kg) |
| Banana | | | | | | | | |
| Mango | | | | | | | | |

**Food security and nutrition of families**

13. Comparing the period before with the after the introduction of the pest, how many months the fruit continues available in the local market?

| Crop | Months of availability in the market | |
|---|---|---|
| | Before | After |
| Banana | | |
| Mango | | |

14. Due to the attack of the pest, have you sent off or reduced the number of temporary workers in your exploration? _____No ______ Yes

If yes, how many permanent workers were sent off and how many temporaries have you reduced?

| | |
|---|---|
| Permanent workers | |
| Temporary workers | |

15. What are other problems you face with the production of fruit?

_______________________________________________________________________________

_____________________________________________________________________________

16. In your exploration, do you have traps to monitor the fruit-fly? No ____ Yes _____ (if yes, fill-in the table below) **THIS TABLE IS MISSING**

## Annex 1B. Survey to the producers of fruit (free zone)

Date____/_____/2012

Province_____________________________ District___________________________

Local ___________________________ Interviewer _____________________

1. Identification data

Name of the producer or company _________________________________________________________

2. Fruits production

| Crop | Area | Number of trees | Orchid age | Yield |
|---|---|---|---|---|
| Banana | | | | |
| Mango | | | | |

3. What is the destination of the production?

Local sale _______ Export ________

4. Market sales

| Crop | Main markets | |
|---|---|---|
| | National | International (export) |
| Banana | | |
| Mango | | |

**Impact of the fruit-fly *Bactrocera invadens***

5. Have you heard of the fruit-fly *Bactrocera invadens*? Yes _____ No ______

If yes,

6. Do you know damages that the pest can cause? Yes _____ No _______

If yes, which are those? ____________________________________________________________________

______________________________________________________________________

7. What is the volume of production sold to the domestic market as well to exports?

| Crop | Domestic market | | Exports | |
|---|---|---|---|---|
| | Quant. (ton) | Price (MT/kg) | Quant. (ton) | Price (MT/kg) |
| Banana | | | | |
| Mango | | | | |

**Food security and nutrition of families**

8. For how many months the fruit is available in the market?

| Crop | Time (months) |
|---|---|
| Banana | |
| Mango | |

9. What are the main problems you face in the production of fruits? Mention in decreasing order of importance

1.________________________________________________________________

2.________________________________________________________________

3.________________________________________________________________

4.________________________________________________________________

## Annex 1C. Survey to producers that own traps in their explorations

**Cost analysis for monitoring the fruit-fly**

| Item | Designation | Unit | Quantity |
|---|---|---|---|
| Number of traps | Q | trap | |
| Distance between traps | Alfa | Km | |
| Area of study (containing traps) | A | $Km^2$ | |
| Cost of maintaining a trap per year | G | $ | |
| Frequency of inspections | Z | times/week | |
| Number of hours of work per inspector | H | hours/week | |
| Velocity of movement of the inspector | V | km/hour | |
| Time of observation | Beta | hours/trap | |
| Average number of traps observed by an inspector | X | trap | |
| Number of inspectors | Li | inspector | |
| Ratio inspector/supervisor | A | | |
| Number of supervisors | Ls | supervisors | |
| Annual average salary of 1 inspector | Wi | $ | |
| Annual average salary of 1 supervisor | Ws | $ | |
| Other additional costs | M | | |
| Cost of vigilance per year | CS | $ | |

## Annex 2. Survey to traders in fruit markets

### A. Information on the Market

Date: ___/___/2012

Name of the market: ____________________ Province: _______________ District: _____________________

Name of the interviewed: __________________________

### B. Origin of the fruit

1. Which are the fruit you sell mostly?

☐ Banana ☐ Mango ☐ Other: ________________________

2. From where come your products?

*(i) Banana*

☐ Own production ☐ Purchase from local producers
☐ Purchase from retailers ☐ Other: ______________________________

*(ii) Mango*

☐ Own production ☐ Purchase from local producers
☐ ☐ Purchase from retailers ☐ Other: ______________________________

### C. Fruit-fly

Have you heard of the fruit-fly?

☐ Yes ☐ No

In which year have you heard for the first time about the fruit-fly? __________________

### D. Sale of fruit

1. **<u>Availability in the local market</u>**

**A. Banana**

*(i)* ***After*** the introduction of the fruit-fly, for how many months do you have Bananas available to sell (indicate the month and relative weight for each month)? ___________

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

*(ii)* ***Before*** the introduction of the fruit-fly for how many months you had bananas available to sell (indicate the month and relative weight per month)?

________

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

**B. Mango**

*(i)* ***After*** the introduction of the fruit-fly, for how many months do you have Mangoes available to sell (indicate the month and relative weight for each month)? ___________

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

*(ii)* ***Before*** the introduction of the fruit-fly for how many months you had mangoes available to sell (indicate the month and relative weight per month)?

________

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

2. **Largest sale season**

**A. Banana**

(i) In which months the sale of Bananas reach its peak (indicate the month and relative weight for each month)?

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

(ii) Quantity of this fruit sold, ***in relation to the period prior (before) the introduction of the fruit-fly*** (indicate the relative proportion):

☐**No-change** ☐**Increased: ________** ☐**Decreased: _________**

**B. Mango**

i. In which months the sale of Bananas reach its peak (indicate the month and relative weight for each month)?

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

ii. Quantity of this fruit sold, ***in relation to the period prior (before) the introduction of the fruit-fly*** (indicate the relative proportion):

☐**No-change** ☐**Increased: ________** ☐**Decreased: _________**

***3.*** **Which are the fruits you sold most during the year of 2011?***(if it was either banana or mango, please skip to question 4)*

______________________________________________________________________

**(i) In which months you sold more of these fruits?**

**Main fruit 1: ______________**

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

The quantity demanded for this fruit, **in relation to the period prior/before the introduction of the fruit-fly:**

☐**No-change** ☐**Increased: ________** ☐**Decreased: _________**

**Fruit 2: __________________**

☐January ☐February ☐March ☐April ☐May

☐June ☐July ☐August ☐September

☐October ☐November ☐December

The quantity demanded for this fruit, **in relation to the period prior/before the introduction of the fruit-fly:**

☐ **No-change** ☐ **Increased: ________** ☐ **Decreased: _________**

4. **Prices for buying and selling the fruit**:

In 2011 which was the price for:
**Banana**________________ **Mango**_____________

5. Before and after the introduction of the fruit-fly, which were the selling prices of banana and mango?
   **Banana**
   Price before_________________ Price after ______________________
   **Mango**
   Price before_________________ Price after ______________________

6. How do you evaluate the price relative to the period before the introduction of the fruit-fly *(indicate the relative proportion)*?

   A. **Banana**

| **Price applied** | **Increased** | **No-change** | **Decreased** |
|---|---|---|---|
| Local producers | ☐ | ☐ | ☐ |
| Retailers | ☐ | ☐ | ☐ |
| Stand (Market) | ☐ | ☐ | ☐ |

   B. **Mango**

| **Price applied** | **Increased** | **No-change** | **Decreased** |
|---|---|---|---|
| Local producers | ☐ | ☐ | ☐ |
| Retailers | ☐ | ☐ | ☐ |
| Stand (Market) | ☐ | ☐ | ☐ |

## Annex 3. Calculation of monitoring costs of the fruit-fly

To calculate the costs of monitoring the fruit-fly it was used a model function of the cost of vigilance described by Florec *et al*. (2010). This model is related with costs generated by the installation of a "Pest Free Area", PFA. For the installation of a PFA in a defined areas A, it is necessary to determine in first place the number of places where traps will be set up to capture the fruit-fly (Q) which is calculated by:

$$Q = \frac{A}{\alpha^2} \qquad (5)$$

here A is the area under study and α is the distance between traps.

The certification and maintenance of a PFA needs trained inspectors who realize observations in those traps. The number of inspectors ($L_I$) needed for a program of vigilance depends on the number of traps to be monitored ($Q$) and the average number of traps that an inspector can inspect in a defined period ($X$). This value depends on the distance between traps (α), the speed of the inspectors' movement between traps ($v$) and the time spent in the observations in each trap (β). Then, the average number of traps that an inspector can inspect in a defined period is pre-determined by:

$$X = \frac{h}{\frac{\alpha}{v} + \beta} \qquad (6)$$

where $h$ is the number of hours of work per inspector during the period of time pre-selected.

Then, the number of inspectors needed to monitor a defined area in a program of vigilance PFA is given by:

$$L_I = z\frac{Q}{X} \qquad (7)$$

where $z$ is the frequency of inspections in a period of time pre-determined (number of times an area is inspected per week, month, etc.).

The number of inspectors is given by:

$$L_I = \frac{zA(\alpha + \beta v)}{\alpha^2 h v} \quad (8)$$

Additionally to the number of inspectors, it may exist other types of technicians' in-charge of supervising the inspectors. Assuming a fixed proportion of the number of supervisors to the number of inspectors, it is calculated the number of supervisors. Then, the number of supervisors ($L_s$) is given by:

$$L_S = \frac{L_I}{a} \quad (9)$$

Then, the total cost of vigilance activities is given by:

$$CS = gQ + L_I w_I + L_S w_S + M(L_I + L_S) \qquad (10)$$

where:

g – cost of maintenance of a trap per year in each place/local;

$w_I$ – annual average salary of an inspector;

$w_s$ - annual average salary of a supervisor;

M – annual average cost of operating the program and other supplemental costs.

## Annex 4. Hosts of *Bactrocera invadens in Africa*

Source: De Mayer *et al*., 2012

| Family | Common name | Scientific name | Country, Reference |
|---|---|---|---|
| Anacardiaceae | Cashew | *Anacardium occidentale* | Benin, Goergen *et al.*, 2011 |
| | Mango | *Mangifera indica* | Western Africa, Goergen *et al.*, 2011 |
| | | | Tanzania 2003, MRAC collection data ; Kenya, Rwomushana *et al.*, 2008a |
| | | *Sclerocarya birrea* | Ekesi *et al.*, 2006<br>Benin, Goergen *et al.*, 2011 |
| | | *Sorindeia madagascariensis* | Kenya, Rwomushana *et al.*, 2008a |
| | Jew plum | *Spondias cytherea* | Tanzania, Mwatawala *et al.*, 2006<br>Benin, Goergen *et al.*, 2011 |
| | Tropical plum | *Spondias mombin* | Benin, Goergen *et al.*, 2011 |
| Annonaceae | Cherimoya | *Annona cherimola* | Kenya, Rwomushana *et al.*, 2008a; Tanzania, Mwatawala *et al.*, 2009 |
| | | *Annona diversifolia* | Ivory Coast, N'Depo *et al*., 2010 |
| | | *Annona montana* | Ivory Coast, N'Depo *et al*., 2010 |
| | Wild custard apple | *Annona senegalensis* | Western Africa, Vayssières *et al.*, 2009a, |
| | | *Annona squamosa* | Kenya, Rwomushana *et al.*, 2008a |
| | Soursop | *Annona muricata* | Ekesi *et al.*, 2006; Vayssières *et al.*, 2009a |
| | | | Tanzania, Mwatawala *et al*., 2006 |
| Apocynaceae | | *Landolphia* sp. | Western Africa, IITA data |
| | Saba nut | *Saba senegalensis* | Cameroon, Goergen *et al.*, 2011 |
| | Lucky nut | *Thevetia peruviana* | Tanzania, Mwatawala *et al.,*2009 |
| Boraginaceae | | *Cordia* sp. cf *myxa* | Kenya, Rwomushana *et al.*, 2008a |
| Caesalpiniaceae | Cayor pear tree | *Cordyla pinnata* | Western Africa, Vayssières *et al.*, 2009a |
| Capparaceae | | *Maerua duchesnei* | Benin, Goergen *et al.*, 2011 |
| Caricaceae | Papaya | *Carica papaya* | Western Africa, Goergen *et al.*, 2011; Tanzania, SUA data |
| Clusiaceae | Chewing stick | *Garcinia mannii* | Cameroon, Goergen *et al.*, 2011 |
| Combretaceae | Tropical almond | *Terminalia catappa* | Ekesi *et al.*, 2006; Benin, Vayssières *et al.*, 2008b |
| | | | Tanzania 2006, MRAC/SUA data |
| Cucurbitaceae | Egusi | *Citrullus* | Benin, Goergen *et al.*, 2011 |

| Family | Common name | Scientific name | Country, Reference |
|---|---|---|---|
| | | *colocynthis* | |
| | Watermelon | *Citrullus lanatus* | Tanzania, Mwatawala *et al.*, 2006<br>Western Africa, Goergen *et al.*, 2011 |
| | | *Cucumis figarei* | Tanzania, Mwatawala *et al.*, 2006 based on single specimen reared |
| | Cucumber | *Cucumis sativus* | Tanzania, Mwatawala *et al.*, 2006<br>Western Africa, Goergen *et al.*, 2011 |
| | Pumpkin | *Cucurbita maxima* | Western Africa, Goergen *et al.*, 2011 |
| | Gourd | *Cucumis pepo* | Western Africa, Goergen *et al.*, 2011 |
| | Bottle gourd | *Lagenaria siceraria* | Benin, Goergen *et al.*, 2011 |
| | Bitter melon | *Momordica charantia* | Western Africa, Goergen *et al.*, 2011 |
| Dracaenaceae | | *Dracaena steudneri* | Kenya 2004, BMNH collection data |
| Ebenaceae | Japanese persimmon | *Diospyros kaki* | Western Africa, IITA data |
| | Mountain persimmon | *Diospyros Montana* | Benin, Goergen *et al.*, 2011 |
| Flacourtiaceae | Governor's plum | *Flacourtia indica* | Tanzania, Mwatawala *et al.*, 2006 |
| Irvingiaceae | African wild mango | *Irvingia gabonensis* | Western Africa, Vayssières *et al.*, 2009a |
| Lauraceae | Avocado | *Persea americana* | Kenya, Ekesi *et al.*, 2006; Tanzania, Mwatawala *et al.*, 2006 |
| | | | Wetsern Africa, Goergen *et al.*, 2011 |
| Moraceae | | *Ficus cf. ottoniifolia* | Benin, Goergen *et al.*, 2011 |
| Musaceae | Plantain | *Musa x paradisiaca* | Western Africa, Goergen *et al.*, 2011 |
| | Cavendish banana | *Musa acuminata* | Benin, Goergen *et al.*, 2011 |
| | | *Musa* sp. | Ekesi *et al.*, 2006 |
| Myrtaceae | Pitanga cherry | *Eugenia uniflora* | Benin, Goergen *et al.*, 2011 |
| | Jambolan | *Syzygium cumini* | Tanzania, Mwatawala *et al.* , 2009 |
| | Rose apple | *Syzygium jambos* | Tanzania, SUA unpublished data<br>Benin, Goergen *et al.*, 2011 |
| | Malay apple | *Syzygium malaccense* | Benin, Goergen *et al.*, 2011 |
| | Java apple | *Syzygium samarangense* | Western Africa, IITA data |
| | Strawberry guava | *Psidium littorale* | Tanzania, Mwatawala *et al.*, 2009 |

| Family | Common name | Scientific name | Country, Reference |
|---|---|---|---|
| | Guava | *Psidium guajava* | Ekesi *et al.*, 2006 |
| | | | Benin, Goergen *et al.*, 2011 |
| | | | Cameroon 2004, MRAC collection data |
| | | | Tanzania 2004, Mwatawala *et al.*, 2006; Kenya, Rwomushana *et al.*, 2008a |
| Oxalidaceae | Carambola, starfruit | *Averrhoa carambola* | Western Africa, Vayssières *et al.*, 2009a |
| Rhamnaceae | Jujube | *Ziziphus mauritiana* | Benin, Goergen *et al.*, 2011 |
| Rosaceae | Loquat | *Eriobotrya japonica* | Tanzania, Mwatawala *et al.*, 2006<br>Cameroon, Goergen *et al.*, 2011 |
| | Apple | *Malus domestica* | Tanzania, Mwatawala *et al.*, 2009 |
| | Peach | *Prunus persica* | Tanzania, Mwatawala *et al.*,2006 |
| Rubiaceae | Arabica coffee | *Coffea arabica* | Tanzania, SUA unpublished data |
| | Robusta coffee | *Coffea canephora* | Tanzania, Mwatawala *et al.*, 2009 |
| | African peach | *Sarcocephalus latifolius* | Westen Africa, Vayssièreset *al.*, 2009a |
| Rutaceae | Sour orange | *Citrus aurantiaum* | Western Africa, IITA data |
| | Pomelo | *Citrus grandis* | Tanzania, Mwatawala *et al.*, 2009 |
| | Lemon | *Citrus limon* | Ekesi *et al.*, 2006<br>Tanzania, Mwatawala *et al.*, 2009<br>Benin, Goergen *et al.*, 2011 |
| | Grapefruit | *Citrus paradisi* | Tanzania, Mwatawala *et al.,* 2006<br>Western Africa, Vayssières *et al.*, 2009a |
| | Tangerine | *Citrus reticulata* | Western Africa, Goergen *et al.*, 2011 |
| | | | Tanzania, Mwatawala *et al.*, 2006;<br>Kenya, Rwomushana *et al.*, 2008a |
| | Sweet orange | *Citrus sinensis* | Western Africa, Goergen *et al.*, 2011;<br>Kenya, Rwomushana *et al.*, 2008a;<br>Tanzania, Mwatawala *et al.*, 2009 |
| | Tangelo | *Citrus tangelo* | Western Africa, Vayssières *et al.*, 2009a |
| | Kumquat | *Fortunella margarita* | Tanzania, Mwatawala *et al.*, 2010 |
| Sapindaceae | Ackee | *Blighia sapida* | Benin, Goergen *et al.*, 2011 |
| Sapotaceae | | *Achra sapota* | Ivory Coast, N'Depo *et al.*, 2010 |
| | White star-apple | *Chrysophyllum albidum* | Benin, Goergen *et al.*, 2011 |
| | | *Chrysophyllum Cainito* | Ivory Coast, N'Depo *et al.*, 2010 |
| | Bully tree | *Manilkara zapota* | Western Africa, Vayssières *et al., 2009a* |
| | | *Richardella campechiana* | Ivory Coast, N'Depo *et al.*, 2010 |

| Family | Common name | Scientific name | Country, Reference |
|---|---|---|---|
| | Sheanut | *Vitellaria paradoxa* | Western Africa, Vayssières *et al., 2009a* |
| Solanaceae | Bell pepper | *Capsicum annuum* | Western Africa, Vayssières *et al.*, 2005 |
| | Chili pepper | *Capsicum frutescens* | Western Africa, Vayssières *et al.*, 2009a |
| | Tomato | *Lycopersicon esculentum* | Ekesi *et al.*, 2006; Mziray *et al.*, 2010<br>Western Africa, Goergen *et al.*, 2011 |
| | African eggplant | *Solanum aethiopicum* | Tanzania, Mwatawala *et al.*, 2009 |
| | African eggplant | *Solanum anguivi* | Tanzania, Mziray *et al.*, 2010 |
| | | *Solanum incanum* | Tanzania, Mziray *et al.*, 2010 |
| | Black nightshade | *Solanum nigrum* | Tanzania, Mziray *et al.*, 2010 |
| | Sodom apple | *Solanum sodomeum* | Tanzania, Mziray *et al.*, 2010 |
| Strychnaceae | | *Strychnos mellodora* | Kenya 2003, R.S. Copeland data |

**Annex 5A. List of producers included in the census and their characteristics (infested zone)**

| NUM | PROV | DIST | LOCAL | EMPR | CROP | AREA | TREE | COMP | AGE | YIELD |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | C.DELGADO | PEMBA | PEMBA | COMACOMA | MANG | 7 | 250 | 20X20 | 32 | . |
| 2 | C.DELGADO | PEMBA | Muxara | lourenço Abudo | MANG | 5 | . | . | 22 | . |
| 3 | NAMPULA | NAMIALO | NAMIALO | Matanunska* | BAN | 1400 | 2,800,000 | . | 4 | . |
| 4 | MANICA | SUSSUNDENGA | DOMBE | GENE-EL | MANG | 74 | 48,000 | 6X2 | 12 | 12 |
| 5 | MANICA | GONDOLA | REVUE | CODFARM/SERGIO YE | MANG | 8 | 4,440 | 6X3 | 3 | 2 |
| 6 | MANICA | SUSSUNDENGA | DOMBE | Pinto Matavel | MANG | 30 | . | 6X3 | 7 | 25 |
| 7 | MANICA | MANICA | MANICA | AGRIZA | BAN | 37 | 77,264 | 2.4X2.1 | 4 | 60 |
| 8 | MANICA | MANICA | MANICA | AUS-MOZ | BAN | 16 | 32,000 | 2.5X2 | . | 26 |
| 9 | MANICA | GONDOLA | MACATE | ASS. PRODUTORES DE MACATE | BAN | 320 | . | 4X2 | 6 | 3 |
| 10 | MANICA | GONDOLA | MARERA | Issufo Valy/Frutis Lda | BAN | 6 | 12,500 | 2.5X1.5 | 2 | 42 |
| 11 | MANICA | SUSSUNDENGA | DOMBE | PASCOAL ALVES/PRESIDENT DA FRUTCENT | MANG | 16 | 8,800 | 6X3 | 7 | 16 |
| 12 | MANICA | GONDOLA | DOMBE | Pedro Paulino | MANG | 24 | 13,200 | 6X3 | 4 | 4 |

*Yields per ha were not provided as they were believed to be confidential data.

**Annex 5B. List of producers included in the census and their characteristics (free zone)**

| NUM | PROV | DIST | LOCAL | EMPR | CROP | AREA | TREE | AGE | YIELD |
|---|---|---|---|---|---|---|---|---|---|
| 1 | MAPUTO | BOANE | UMBELUZI | DOMINGOS COELHO | MANGO | 6 | 100 | 7 | 2 |
| 2 | MAPUTO | BOANE | GUEGUEGUE | Muthemba | MANGO | 1.5 | 445 | 8 | 19 |
| 3 | MAPUTO | BOANE | BOANE | BANANALANDIA | BAN | 138 | 303,600 | 5 | 55 |
| 4 | MAPUTO | BOANE | LIBOMBOS | CITRUM | BAN | 70 | . | 3 | . |
| 4 | MAPUTO | BOANE | LIBOMBOS | CITRUM | CITRUS | 80 | . | . | . |
| 5 | MAPUTO | BOANE | UMPALA | RIO VERDE | BAN | 530 | . | 10 | 52 |
| 6 | MAPUTO | MOAMBA | SABIE | AGRISUL | BAN | 105 | 220,000 | 4 | 60 |
| 7 | MAPUTO | MOAMBA | MOAMBA SEDE | SAMORA | BAN | 1.5 | . | 1 | 4 |
| 8 | MAPUTO | CATUANE | CATUANE | TRES RIOS* | LITCH | 78 | | 3 | 60 |
| 9 | GAZA | GUIJA | MUBANGUENE | ROQUE | BAN | 2 | . | 3 | 11 |
| 10 | MAPUTO | MANHIÇA | MANGUENE | ASSOC. G21 | BAN | 67 | | 3 | 7.2 |
| 11 | GAZA | GUIJA | CHIVANJOENE | AFRICAN FOOD COMPANY* | BAN | 300 | 624,900 | | |
| 12 | GAZA | GUIJA | DJAVANHANE | ANASTACIO TIVANE | BAN | 1.5 | | 5 | 2 |
| 13 | GAZA | chokwe | chokwe | matuba emvest* | | | | | |
| 14 | GAZA | chokwe | chokwe | mutombene | BAN | 5 | | 5 | 8 |

*These companies are not yet producing due to the young age of their orchids.

## Annex 6. Results of the "t" test

Table xxx. "t" test paired for the difference in **average production** of **banana** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | prodant | Proddep | Dif | df | std. Err. | t | Pr(T>t) |
| 8 | 1050.5 | 1004.25 | 46.25 | 7 | 30.27 | 1.53 | 0.0852 |

Table xxx. . "t" test paired for the difference in **average production** of **mango** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | prodant | Proddep | Dif | df | std. Err. | t | Pr(T>t) |
| 7 | 645.143 | 602.285 | 42.86 | 6 | 27.66 | 1.55 | 0.0862 |

**The result if the "t" test for the average number of workers, permanent and seasonal, employed by the banana and mango farms in the northern region of the country**

Table xxx. "t" test paired for the difference of the average number of **permanent workers** employed by farms in the production of **banana,** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | Trefant | trefdp | Dif | df | std. Err. | t | Pr(T>t) |
| 7 | 18 | 15.4 | 2.6 | 6 | 1.66 | 1.55 | 0.0852 |

Table xxx. "t" test paired for the difference of the average number of **permanent workers** employed by farms in the production of **mango,** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | Trefant | trefdp | Dif | df | std. Err. | t | Pr(T>t) |
| 7 | 16.5 | 15.2 | 1.3 | 6 | 2.40 | 0.55 | 0.2971 |

Table xxx. "t" test paired for the difference of the average number of **seasonal workers** employed by farms in the production of **banana,** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | prodant | Proddep | Dif | df | std. Err. | t | Pr(T>t) |
| 7 | 128.6 | 74.3 | 54.30 | 6 | 23.23 | 2.33 | 0.0293 |

Table xxx. "t" test paired for the difference of the average number of **seasonal workers** employed by farms in the production of **mango,** before and after the introduction of the fruit-fly

| | Means of variables | | | | | | |
|---|---|---|---|---|---|---|---|
| obs | prodant | Proddep | Dif | df | std. Err. | t | Pr(T>t) |
| 7 | 25 | 21.7 | 3.30 | 6 | 4.41 | 0.76 | 0.2357 |

## Annex 7. Results of the monitoring costs

**Analysis of the annual cost of monitoring (materials and staff)**

| Item | Unit | Quant. | Unit cost (MT) | Total cost (MT) |
|---|---|---|---|---|
| Traps | Trap | 372 | 84 | 31,248 |
| Insecticide | Kit | 200 | 140 | 28,000 |
| Pheromone | Kit | 200 | 140 | 28,000 |
| Staff | Person | 8 | 10,000 | 960,000 |
| **Sub - Total 1** | | | | **1,047,248** |

**Analysis of the vigilance costs**

| Item | Designation | Unit | Value |
|---|---|---|---|
| Number of traps | Q | trap | 372 |
| Distance between traps | Alfa | Km | 1 |
| Area under study (containing traps) | A | Km2 | |
| Cost of maintenance of 1 trap per year | G | ($?)MT | 7,700 |
| Frequency of inspection | Z | Number of times/month | 1 |
| Hours of work per inspector | H | Hours/month | 8 |
| Speed of movement of the inspector | V | Km/hour | 60 |

| | | | |
|---|---|---|---|
| Time of observation | Beta | Hours/trap | 0.4 |
| Average number of traps inspected per inspector | X | Trap | 19.2 |
| Number of inspectors | Li | Inspector | 8 |
| Ratio inspector/supervisor | A | | |
| Number of supervisors | Ls | Supervisor | 1 |
| Annual cost of a vehicle (fuel) | M | $/MT | 300,000 |
| Annual average salary of 1 inspector | Wi | $/MT | 240,000 |
| Annual average salary of 1 supervisor | Ws | $/MT | 360,000 |
| Vigilance cost per year | CS | $/MT | 7,844,400 |

| | |
|---|---|
| **Total Cost (sub-total 1 + vigilance cost)** | **8,891,648** |

## Annex 8. List of traders interviewed

| NUM | PROV | DIST | MARKET | INTERV | FRUIT |
|---|---|---|---|---|---|
| 1 | manica | sussundenga | 1 maio | denisio | Banana |
| 2 | manica | sussundenga | 1maio | rosalina | Banana |
| 3 | manica | sussundenga | 1maio | isabel | Banana & Mango |
| 4 | manica | gondola | zembecentro | sarita | Banana & Mango |
| 5 | manica | gondola | zembecentro | maria | Banana & Mango |
| 6 | manica | gondola | zembecentro | gloria | Banana & Mango |
| 7 | manica | gondola | zembecentro | cristina | Banana |
| 8 | nampula | nampula | central | jorge walikela | Banana |
| 9 | nampula | nampula | waresta | abdul mansoor | Banana |
| 10 | nampula | nampula | waresta | aristides francisco | Banana |
| 11 | cabodelgado | metuge | miese | muhando | Banana & Mango |
| 12 | cabodelgado | metuge | miese | mateus | Banana, Mango Citrus |
| 13 | manica | manica | 38 | anita inicio | Banana |
| 14 | manica | gondola | paragem control | rosa fabiao gonsalves | Banana |
| 15 | manica | gondola | mafolga | alberto | Banana |
| 16 | manica | chimoio | praca ngungunhana | bernardo | Banana |
| 17 | manica | chimoio | 38 | vitoria | Banana |
| 18 | manica | chimoio | 38 | rosa | Banana |
| 19 | manica | chimoio | 38 | cristina joao | Banana |
| 20 | manica | chimoio | 38 | maria sari | Banana |
| 21 | manica | gondola | marera | celina manuel | Banana |
| 22 | manica | gondola | marera | amelia | Banana |
| 23 | manica | gondola | mussunza | francisca | Banana |
| 24 | manica | gondola | mussunza | chica carlos | Banana |
| 25 | manica | gondola | braundi | pedro | Banana, Mango, citrus |
| 26 | manica | gondola | braundi | joao antonio | Banana |
| 27 | manica | gondola | mussunza | samuel vasco | Banana |
| 28 | cabodelgado | metuge | miese | amor ali | Banana & Mango |
| 29 | nampula | nampula | central | samuel sabonete | Banana & citrus |
| 30 | nampula | nampula | waresta | mauleto | Banana |
| 31 | nampula | nampula | waresta | adelino alfredo | Banana |
| 32 | nampula | nampula | waresta | simoes joao | Banana & citrus |
| 33 | nampula | nampula | waresta | lourenco zacarias | Banana & citrus |
| 34 | nampula | nampula | central | delivio raste | Banana |
| 35 | nampula | nampula | central | mauricio lino | Mango & citrus |
| 36 | nampula | nampula | central | eduardo pinto | Banana |
| 37 | cabodelgado | chiure | chiure | luis | Banana, Mango, citrus |
| 38 | cabodelgado | metuge | miese | dalique iaya | Banana & citrus |

| NUM | PROV | DIST | MARKET | INTERV | FRUIT |
|---|---|---|---|---|---|
| 39 | cabodelgado | metuge | miese | eugenio cruz | Banana, Mango, citrus |
| 40 | cabodelgado | metuge | miese | anonimo | Banana, Mango, citrus |
| 41 | cabodelgado | pemba | portao wimbe | lucio dinis | Mango, citrus |
| 42 | cabodelgado | chiure | mahipa | anonimo | Banana, Mango, citrus |
| 43 | cabodelgado | chiure | mahipa | norberto cardeal | Banana, Mango, citrus |
| 44 | cabodelgado | chiure | mahipa | elisa antonio | Mango, citrus |
| 45 | cabodelgado | metuge | miese | orlando benjamim | Banana, Mango |
| 46 | cabodelgado | metuge | miese | catarina hugo | Banana |
| 47 | cabodelgado | metuge | komakoma | maria assupa | Banana, Mango |
| 48 | cabodelgado | chiure | mahipa | dias tawira | Banana, Mango, citrus |
| 49 | cabodelgado | chiure | chiure | manuel altino | Citrus |
| 50 | cabodelgado | metuge | komakoma | lucia antonio | Mango |
| 51 | cabodelgado | metuge | komakoma | amade | Mango |
| 52 | cabodelgado | metuge | komakoma | sara ussene | Mango & citrus |
| 53 | cabodelgado | metuge | miese | aly | Banana, Mango, citrus |
| 54 | cabodelgado | metuge | muxara | rodrigues nacarroa | Banana, Mango, citrus |
| 55 | cabodelgado | pemba | embondeiro | assane valy | Mango |
| 56 | cabodelgado | pemba | embondeiro | vasco maria | Mango & citrus |
| 57 | cabodelgado | pemba | batatas | alique | Mango |
| 58 | cabodelgado | pemba | batatas | joao pedro | Mango & citrus |
| 59 | cabodelgado | pemba | batatas | costa momade | Banana, citrus |
| 60 | cabodelgado | pemba | embondeiro | rafique jala | Mango |
| 61 | cabodelgado | pemba | embondeiro | anonimo | Manga, citrus |
| 62 | cabodelgado | pemba | batatas | sousa | Citrus |
| 63 | cabodelgado | pemba | centro cidade | amina | Banana |
| 64 | cabodelgado | pemba | centro cidade | luisa luis | Banana |
| 65 | cabodelgado | pemba | centro cidade | anonimo | Citrus |
| 66 | maputo | boane | unidade | james | banana,tangerine |
| 67 | maputo | boane | boane | carolina | Banana |
| 68 | maputo | boane | unidade | joana | banana,grapefruit |
| 69 | maputo | boane | boane | anita macuacua | banana,mango |
| 70 | gaza | chokwe | hospital | | banana,mango |
| 71 | gaza | guijá | central | laurinda cossa | banana,tangerine,mango |
| 72 | inhambane | inharrime | inhacoongo | merito nhampossa | banana,mango,citrus |
| 73 | inhambane | inharrime | Inharrime | Anónimo | banana,pineapple |
| 74 | maputo | moamba | sabie | celia andre | Banana |
| 75 | maputo | moamba | sabie | mariamo cossa | Banana |
| 76 | maputo | moamba | moamba | sofia | banana,mango,citrus,apple,grapes |
| 77 | maputo | moamba | moamba | anonimo | Banana |
| 78 | maputo | moamba | moamba | olinda | banana, mango & citrus |
| 79 | maputo | moamba | sabie | rosalina tembe | Banana |